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FOOD SYSTEMS AT RISK

Transformative Adaptation for Long-Term Food Security

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FOREWORD

Food security, people, climate. These three words are inextricably linked; changes to one will inevitably affect the others. As climate change threatens food-producing regions, what changes are needed to feed a growing population? How can we shift food systems to better adapt to the changing climate? More explicitly, how can policymakers help hundreds of millions of small-scale agricultural producers to enhance food security and improve livelihoods despite the challenges that climate change brings?

Food Systems at Risk: Transformative Adaptation for Long-Term Food Security addresses these questions. It offers policymakers, funders, and researchers bold recommendations to advance transformative approaches by leveraging new types of data and analytical tools and rethinking how we plan and invest. The report authors synthesized dozens of research studies on how climate change is affecting food systems. They also interviewed farmers, government officials, and decision-makers in financial institutions and agricultural support and research organizations.

The report highlights how climate change will negatively impact food systems, particularly in climate hotspots such as semi-arid and desert regions in India and sub-Saharan Africa, coastal rice paddy regions in Bangladesh and Vietnam, and glacier and snow-fed agricultural areas in Peru and the Himalayas. It finds that incremental adaptation, while important, will be insufficient to avert dramatic increases in hunger, poverty, and displacement over the next 30 years. Instead, greater commitments to plan, fund, and implement transformative adaptation measures will be essential to ensure food security.

As this report illustrates, transformative approaches to agricultural adaptation will mean continually shifting the locations of where specific types of crops and livestock are produced to areas with more suitable climatic conditions – for example, grain farmers in Ethiopia moving staple crops such as maize to higher elevations as temperatures rise. It will also require changing agricultural production systems to better fit changing landscapes and ecosystems, such as rice growers in Bangladesh shifting to aquaculture in response to increased salinity due to rising sea levels and reduced seasonal river flows. Innovative production methods and technologies, such as low-cost greenhouses that help Indian vegetable farmers to conserve water and protect their produce from storm damage, will also be needed to promote long-term resilience.

As policymakers, funders, and researchers address climate change challenges in local, national, and global food systems, it will be critical that smallholder farmers and their community leaders have a voice in identifying solutions through participatory and inclusive planning processes. This report offers examples and recommendations on how to implement a transparent and participatory process for transforming agriculture for climate resilience.

This new WRI report builds on the Global Commission on Adaptation's flagship report, *Adapt Now: A Global Call for Leadership on Climate Resilience*. Together, these two reports offer a comprehensive, long-term perspective and recommendations for how to transform global agricultural systems to be more resilient, productive, and equitable in the face of growing climate challenges.

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EXECUTIVE SUMMARY

Climate change impacts are already reducing crop and livestock productivity and decreasing food security for millions of people around the world—and these impacts will intensify over the coming decades. Longer-term, systemic, transformative approaches to adaptation are needed to protect rural lives and livelihoods. This report explores how climate change is affecting agriculture and the benefits that transformative approaches to adaptation offer.

HIGHLIGHTS

- Strategic investments in resilient food systems are crucial to manage intensifying climate change impacts and feed 9.7 billion people by 2050.
- In some geographical hotspots climate change is already undermining food systems, even where incremental adaptation measures are ramping up.
- Beginning now to anticipate, plan for, and expand financing options through *transformative adaptation* is critical to averting and minimizing loss and damage; enhancing global food security; reducing risks of displacement, conflict, and crisis; and avoiding maladaptation.
- The authors define transformative adaptation in agriculture as promoting long-term resilience by continually shifting the geographical locations where specific types of crops and livestock are produced, aligning agricultural production with changing landscapes and ecosystems, and/or introducing significantly new resilience-building production methods and technologies at broad scale across value chains.
- Planning for transformative adaptation should center on inclusive, participatory processes that engage a diverse range of stakeholders who may often be marginalized in decision-making, such as women, youth, and Indigenous peoples.
- After taking stock of the evidence regarding the harsh impacts on agriculture anticipated from warming of 1.5 or 2 degrees Celsius (°C) or higher over the coming decades, this report presents evidence to support a call for urgent action by
  - **agricultural research organizations**, to build and share knowledge regarding transformative approaches;
  - **governments**, to integrate this knowledge into plans and policies by establishing and implementing *transformative pathways*; and
  - **funding entities**, to increase financial support for agricultural adaptation and design sustainable financing mechanisms with the right incentives and disincentives to support transformative adaptation.

Context

As climate change impacts intensify, hard-won development gains are already being undermined. After a decade of decline, global hunger is rising, with nearly 60 million more undernourished people than in 2014—an increase in the global prevalence of undernutrition from 8.6 to 8.9 percent of the world's population—which is attributable in part to greater climate variability and more extreme weather events (FAO 2020a). In the coming decades, the impacts of climate change on the productivity of crops, livestock, fisheries, and forestry will become more severe (Gourdji et al. 2013; IPCC 2014), while the global human population is expected to expand to 9.7 billion by 2050 (UNESA 2019).

Currently, most agricultural adaptation focuses on scaling up incremental measures. The Intergovernmental Panel on Climate Change (IPCC) defines such measures as "actions where the central aim is to maintain the essence and integrity of the **existing** technological, institutional, governance, and value systems, such as through adjustments to cropping systems via new varieties, changing planting times, or using more efficient irrigation" (IPCC 2014, 839; emphasis added). While such measures are extremely important and valuable, evidence is mounting that incremental measures alone will not adequately protect farmers, fishers, herders, and other rural people from growing risks as climate change impacts intensify. *Transformative adaptation*, which the IPCC refers to as an approach that "seeks to **change the fundamental attributes of systems** in response to actual or expected climate change and its effects, often at a scale and ambition greater than incremental activities," is an essential complement. The IPCC goes on to note that transformative adaptation includes measures "such as changing livelihoods from cropping to livestock or by migrating to take up a livelihood elsewhere, and also changes in our perceptions and paradigms about the nature of climate change, adaptation, and their relationship to other natural and human systems" (IPCC 2014, 836; emphasis added).

In some locations, the limits of incremental adaptation are already being tested, with permanent implications for the long-term viability of local food systems. Risks are especially high in sub-Saharan Africa, South Asia, and small island developing nations (SIDS), and for vulnerable groups such as women, youth, Indigenous peoples, and people living in poverty, among others.

Box ES1 offers a few examples of transformative adaptation from around the world.

New approaches to adaptation are needed where current systems will not be able to support existing agricultural livelihoods under future climate stresses. This report explores one of them—transformative adaptation—and concludes that it is critical to avert and minimize loss and damage while enhancing global food security; reducing escalating risks of displacement, conflict, and crisis; and avoiding maladaptation.

BOX ES1 | Examples of Transformative Adaptation

Costa Rican coffee farmers in areas that are becoming too warm for coffee production are shifting to citrus instead.[a]

Farmers in Bagerhat District, Bangladesh, have shifted from rice production to aquaculture in response to increased salinity due to saltwater inundation from the sea and reduced seasonal river flows.[b]

In southeast Kazakhstan, increasingly scarce water supplies have been reallocated to less water intensive crops in response to reductions in snow cover and water supply with the intention of shifting the mix of crops grown in the region.[c]

In Ethiopia, cultivation of staple crops including wheat and teff has been moving to higher elevations as temperatures rise, while maize is replacing these crops and being grown more widely.[d]

In Uttarakhand, India, mountain farming villages affected by increased rainfall variability are being abandoned and reverted to forest or pastureland while more people engage in intensive agriculture in river valleys or shift to nonagricultural livelihoods.[e]

In Northeast India, dragon fruit has been successfully cultivated for the first time due to hotter and drier climate conditions.[f]

Notes: a. Ferdinand et al. 2020; b. Faruque et al. 2016; c. Barrett et al. 2017; d. Tan et al. 2016; e. IMI 2019; f. Thokchom et al. 2019.

About This Report

The Transforming Agriculture for Climate Resilience (TACR) project, funded by the Bill & Melinda Gates Foundation, aims to increase investments in agricultural adaptation and strengthen our collective understanding of and support for transformative approaches to adaptation where and when they are needed. This report is based on three years of research to delineate the following: what transformative adaptation is and how it applies to agriculture; why it is needed and what benefits it can offer; and how it can be better integrated into research, policy, planning, and funding processes to build the long-term resilience of farmers, herders, and others involved in agricultural value chains.

The TACR project recognizes that risks are increasing for ecosystems and regions as described in the 2019 IPCC *Global Warming of 1.5°C* report (see Section 2.4 of this report; IPCC 2019). Such threats mean that some "natural, managed and human systems" around the world, including crop yields, will experience severe and widespread climate change impacts and risks as temperatures exceed 2°C—which more recent research (Sherwood et al. 2020) indicates is highly likely to occur. Other systems that humans depend on for food security, such as warm-water coral reefs and tropical freshwater fisheries, as well as coastal areas that are home to 10 percent of the world's population, are already facing tipping points.

In these ecosystems and regions, severe, irreversible climate change impacts will increase as temperatures rise and the limitations of adaptation are reached (IPCC 2019). These tipping points are likely to drive some systems to the point that they cannot continue to exist in their current form—including the food systems of an increasing number of places. In these situations, fundamental, systemic transformation is needed. Anticipating, planning for, and financing these transformations will require answering an important set of questions:

- How can we better identify, anticipate, and address situations where climate change impacts have already or will soon exceed the resilience that incremental adaptation measures can provide?
- How can we build the understanding, capacity, and technical knowledge needed to recurrently match the right crops and livestock varieties and production methods with farmers who face continually evolving conditions, while also ensuring that other vital components of value chains—such as processing, marketing, and distribution—can keep pace with these changes and support such significant shifts?
- How can we design, establish, finance, and implement *transformative pathways* (i.e., coordinated sequences of short- and medium-term actions or projects intended to prepare food systems for unprecedented climate conditions) so that those most vulnerable to climate change are part of decision-making?

The TACR project set out to determine how fundamental, systemic transformation can be achieved. As described in greater detail in Section 1.2, the TACR project began with an extensive review of published academic literature on agricultural transformation and adaptation, as well as a review of publications from and consultations with representatives of the key audiences for this report: agriculture and adaptation researchers, governments, and adaptation funding entities. Examples of funding entities include multilateral institutions such as the Green Climate Fund, the Adaptation Fund, and the World Bank, as well as bilateral donors like the U.S. Agency for International Development, the German Federal Ministry for Economic Cooperation and Development, and the British Foreign, Commonwealth & Development Office. Based on this research, a framework that included a workable definition for transformative adaptation in agriculture was established (Carter et al. 2018). This framework was then applied in three working papers on key agricultural topics: crop research and development (Niles et al. 2020), livestock production (Salman et al. 2019), and climate services (Ashley et al. 2020). World Resources Institute (WRI) researchers also applied the TACR framework to coffee production in Costa Rica (Tye and Grinspan 2020) and tested it on locally led climate-driven transformations in Costa Rica, Bhutan, and Ethiopia (Ferdinand et al. 2020).

This synthesis report is based on the framework and working papers mentioned above. It also reflects an ongoing series of interviews and consultations with experts in agricultural adaptation from state and national government agencies and agricultural research organizations in Ethiopia and India. Input from adaptation funding entities was gathered on an ad hoc basis over the course of the research. Preliminary findings were discussed and enriched during panel discussions and workshops at United Nations Framework Convention on Climate Change (UNFCCC) events and other relevant public fora.

The paper also includes updated analyses based on new research such as the IPCC *Global Warming of 1.5°C* report (IPCC 2019). It takes a deeper look at the need for agriculture to shift in alignment with climate-driven ecosystem changes, as well as new linkages to the UNFCCC discussion on loss and damage. It also includes an economic model constructed by WRI researchers to determine when transformation makes economic sense.

The framework, working papers, and this synthesis report largely focus on the need for "top-down" action by research organizations, governments, and adaptation funding entities to better support smallholder farmers, herders, and fishers and marginalized communities to engage in more widespread transformative adaptation. Examples are emerging of locally led, or *autonomous*, transformative adaptations to climate change, in which local residents respond to climate change impacts (often among other drivers) without external support or guidance. However, our research indicates that the number of "pioneer farmers" and communities with the ability to make transformative changes without external assistance is quite limited. They tend to be those with greater

access to resources (e.g., land, credit, information, technical capacity) with which to manage increasing climate risks. Implementing the elements of transformative adaptation for agriculture—i.e., shifting the locations where specific types of crops and livestock are produced, aligning agricultural production with changing landscapes and ecosystems, and/or introducing innovative production methods and technologies suitable for significantly changed conditions—is difficult for most farmers and communities to do on their own. This is especially true for those that are most vulnerable to climate change impacts: people living in poverty and other often marginalized groups including women, youth, and Indigenous peoples. While large agribusinesses with ties to global supply chains may have the financial, technical, and other resources needed to effectively engage in transformative adaptation, these more vulnerable groups often require external support to do so, and are therefore the focus of this paper. While the private sector writ large will need to respond to climate change and can promote and incentivize building agricultural resilience, it is less often a source of assistance for these most vulnerable groups than are organizations with a public mandate to ensure that no one is left behind.

While the TACR project was underway, the Global Commission on Adaptation was formed, with the aim of inspiring heads of state, government officials, community leaders, business executives, investors, and other international actors to prepare for and respond to the disruptive effects of climate change with urgency, determination, and foresight. The commission launched its flagship report *Adapt Now: A Global Call for Leadership on Climate Resilience* in September 2019 (Bapna et al. 2019), and engaged in 2020 in a Year of Action on eight action tracks, including one focused on agriculture and food security. This report refers often to *Adapt Now* to suggest ways that transformative approaches to agricultural adaptation can be carried forward.

This report's recommendations are intended to encourage adaptation funding entities, governments, and research organizations to make long-term, systemic—i.e., transformative—approaches to resilience possible, especially for the poorest and most vulnerable farmers, by including such approaches in plans, projects, policies, and investment agendas. Promoting and supporting resilience will improve the odds of reducing risk and improving sustainability over the short term (less than 5 years), medium term (5 to 10 years), and long term (over 10 years).

Calls to Action

Based on the evidence it presents, this report calls for funding entities, governments, and research organizations to better understand, plan for, and finance transformative approaches to adaptation for food systems. The following three priorities expand on the "three revolutions" introduced by the Global Commission on Adaptation's *Adapt Now* report (Bapna et al. 2019) to adequately factor climate change impacts and risks into key decisions through improved understanding, planning, and financing.[1]

1. **Understanding through expanded research and development**

Research and development must be expanded to make climate risks visible over multiple timescales and geographies and engage farmers, fishers, and herders in identifying transformative solutions for building long-term resilience.

- **Research efforts must focus squarely on the needs, experiences, and solutions of people living in poverty and others most vulnerable to climate change impacts—especially small-scale producers.** This includes ensuring that these groups, and particularly Indigenous peoples, can contribute their knowledge and add to the evidence base regarding which adaptation measures will work best in their particular contexts, as well as facilitating their access to information. Poor and other vulnerable communities must have a voice in decision-making regarding systemic shifts at all links in value chains, so that their knowledge, expertise, needs, and preferences can shape actions, and so that no one is left behind. This will require strengthening their capacity to access and translate longer-term climate change projections so that they can better choose options that will serve them and their families over the coming decades—including whether and when to encourage the next generation to choose different livelihoods if climate projections indicate that agriculture will no longer be tenable in their area. Inputs required for transformative adaptation—e.g., new types of crops, fish, and livestock along with the information, skills, inputs, and financing required to successfully produce and market them—must be made accessible to these groups, particularly those living in poverty. Moreover, perceived risks of trying new crops and production methods must be tempered. Investments are needed to improve the resilience and productivity of traditional crops that may not appear in global supply chains but are essential to local food security and nutrition. Involving stakeholders and minimizing barriers to implementing resulting strategies will require greater collaboration with and participation from farmers, herders, fishers, and local communities who are the on-the-ground implementers of adaptation action (Ferdinand et al. 2020; Tye and Grinspan 2020).

- **The research agendas of global research systems, such as the Consultative Group on International Agricultural Research (CGIAR); National Agricultural Research Systems; and especially local research institutions and organizations that work closely with farmers should expand to promote transformative adaptation approaches across food, land, and water system shifts (Ashley et al. 2020), with support from governmental agricultural policy, planning, and extension offices.** Local organizations in particular, including producers' associations, need greater capacity to encourage farmers to experiment with new types of crops and livestock and other transformative elements. A greater share of funding must be channeled to them to support work to identify what will work in particular contexts. Current gaps for all types of research entities include speeding up the development-to-adoption timeframe of new crop and livestock varieties by improving infrastructure and technology exchanges; expanding pest and surveillance networks; improving access to meteorological and water supply and demand data, as well as data on soil health; and engaging in intersectoral and interregional coordination platforms (Salman et al. 2019; Niles et al. 2020). More attention should be given to improved breeding of livestock and orphan crops rather than continuing to invest mostly in research on global staple cereal crops like rice, wheat, and maize. Finally, capacity must be built to undertake a broader range of analyses including accounting for externalities (i.e., hidden costs, often to environmental sustainability), trade-offs, and co-benefits; social impacts; political economy; and foresight analysis. The last of which has been defined as "a systematic, participatory, future-intelligence-gathering and medium-to-long-term vision-building process aimed at enabling present-day decisions and mobilizing joint action" (UNDP 2014, 7).

- **Research organizations, with support from governments and funding entities, should enhance climate services and information platforms with new types of information to identify hotspots and aid decision-makers in designing transformative pathways.** This necessitates providing easily understandable information with greater consideration for slow-onset events and decadal and longer-term data and projections (Ashley et al. 2020); more transparent data around intersectoral trade-offs on natural resource use, prices, and market models (Tye and Grinspan 2020); and other non-climate variables important for planning and prioritization (Ashley et al. 2020). Also needed are more robust baseline data collection and greater availability and accessibility of high-resolution, contextualized data on climate change impacts (Ashley et al. 2020). Improved climate-crop suitability models and analyses are a prerequisite to increasing understanding of which varieties and species will lose and gain suitability in different regions (Ashley et al. 2020; Niles et al. 2020). Information on broader production conditions, markets, and other types of risks to agriculture could be added in to enable a more holistic risk assessment.

2. **Planning (and implementation) to improve policy and investment decisions**

Coordination must be improved among governments, adaptation funding entities, and research organizations to create and finance transformative pathways in a way that is coherent, inclusive, and participatory, and based on an understanding of existing political economies. This could be done by, for example, leveraging national development plans, United Nations Sustainable Development Goals, and readiness programs (Carter et al. 2018).

- **National and subnational governments should integrate an understanding of when, where, and how food systems will need to shift over the coming decades into their planning processes and use inclusive, participatory processes to design transformative pathways so that smallholder farmers, herders, and fishers and rural communities are not left behind.** Addressing the need for long-term, systemic change may be politically risky and unattractive when attention is focused on the next election rather than decades in the future, but its potential for providing food security and improving livelihoods may reduce future conflicts and chaos, which makes it a worthwhile endeavor. If done well, such changes can also pave the way for investments in new job-generating businesses and improved incomes based on growing and processing novel agricultural products. Governments should phase in longer-term planning based on transparent information and in consultation with a range of stakeholders, rather than waiting for increasingly frequent crises to make further delays impossible. Effectively designing transformative pathways requires that government agencies integrate research and analysis into plans, policies, budgets, and funding proposals. Institutional arrangements must promote collaboration and reduce fragmentation among ministries and departments so that many systems—e.g., water, trade, employment, finance—can operate across boundaries, both geographical or political, as well as at different scales, from local to national and beyond.

- **Planning for transformative adaptation should center on inclusive, participatory processes that engage a diverse range of stakeholders, including smallholder farmers, fishers, and herders from groups that may often be marginalized in decision-making, such as women, youth, and Indigenous peoples.** Transformative change will almost always be challenging because what farmers and herders produce is often central to their identity, sense of

place, and pride. Even so, agroecological conditions will inevitably change around them. They should be the ones making the difficult decisions about how to manage such changes—and supported even when this means finding nonagricultural livelihoods. Participatory governance structures that facilitate effective two-way communication from the local to national level are needed, as well as sufficient financial and technical support for communities to enact food system shifts. Strengthening farmer-focused organizations like cooperatives, producer organizations, and community savings groups will be helpful in many situations. While there are cases of autonomous transformative adaptations already taking place, research indicates that it is often those with more land and better access to credit and information that are able to make such changes on their own. This points to the need to provide better support to people who are living in poverty or who are otherwise marginalized and improve their access to resources required for transformative adaptation (e.g., credit, information, inputs) so they can have a wider range of choices, better manage risk, and make decisions about their futures under new climatic conditions.

- **The UNFCCC, as well as international organizations like CGIAR and the Food and Agriculture Organization (FAO) of the United Nations, can facilitate and catalyze the development, dissemination, and use of knowledge to advance transformative adaptation policies and practices.** The imperative toward long-term, systemic shifts should be part of ongoing discussions focused on loss and damage,[2] the Nairobi Work Programme, the Koronivia Joint Work on Agriculture, nationally determined contributions, national adaptation plans, and long-term strategies. Little guidance and few examples are available to Parties on how to incorporate transformative approaches to adaptation in their plans, policies, and funding proposals. UNFCCC entities can play an important role in creating and disseminating this information and showcasing best practices. In addition, global agricultural organizations like CGIAR and FAO can contribute their agricultural and climate expertise to speed implementation.

3. **Finance to mobilize resources to accelerate transformative adaptation**

Given the challenges that the global food system faces, a massive increase in funding for agricultural adaptation is urgently needed, for both incremental and transformative approaches. While the costs of transformative adaptation have not yet been calculated, its potential for averting and minimizing

losses and damages makes it likely to pay off over the longer term. More specific actions include the following:

- **Adaptation funders, including bilateral and multilateral agencies, need to develop complementary understandings of transformation and shift their funding approaches** to support projects and programs that prioritize building resilience in hotspots where systemic tipping points make fundamental changes urgent. Such an understanding can be achieved through deeper engagement with peer organizations, leveraging each entity's comparative advantages, and broadening the focus from isolated projects to more comprehensive programs. Funding entities can incentivize governments to incorporate transformative adaptation into planning efforts by including it in their funding guidelines and potentially offering special funds to cover this.

- **Governments and the private sector must refocus the use of incentives and disincentives to initiate and sustain adaptive shifts in food systems.** Governments and the private sector, particularly banks and financiers, could create market incentives and disincentives such as taxes, fixed pricing, and other market mechanisms to provide opportunities (or remove barriers) for farmers to invest in unfamiliar and potentially risky transitions to other types of agricultural (or nonagricultural) livelihoods (Niles et al. 2020). Grants, loans, subsidies, taxes, pricing policies (such as minimum support pricing or energy and water pricing), and improved co-financing tools, among others, could be effective in changing farmer choices and providing farmers with opportunities to invest in such transformations (Bapna et al. 2019)—these tools could be made more effective by making them more accessible and tailoring them to support transformative adaptation. Improved access to insurance could make taking the risks of trying new types of crops and livestock or new production and processing methods more acceptable. Redesigning subsidy structures for new crops and their inputs, offering grants for de-risking experimentation with crops likely to prove more resilient, promoting marketing campaigns, and encouraging selective seed market intensification are additional options to encourage adaptive crop and livestock switches (Niles et al. 2020).

When considering parameters of adaptation interventions, multilateral and bilateral adaptation funding entities need to expand their financing modalities to encourage and support comprehensive, long-term adaptation programs that recognize the interconnectedness of food systems with other systems, and governments need to include this approach in their budgets and proposals. For example, longer-term funding (e.g., 10 years instead of 5) would cover the sequential but continuous changes required to implement transformative pathways. Financing packages could include the private sector and be scaled at the right geographical level (e.g., farming system); acknowledge ecological considerations (e.g., humid tropical regions becoming semi-arid); and incorporate existing institutions and socioeconomic factors (e.g., civil society, research and development networks, markets, cultural considerations).

CHAPTER 1

TRANSFORMING AGRICULTURE TO MEET THE CLIMATE–FOOD SECURITY CHALLENGE

Countries around the world committed to ending hunger and to achieving climate-resilient, low-carbon development when they signed the Paris Agreement in December 2015 and the 2030 Agenda on Sustainable Development in January 2016.

The urgency of ramping up adaptation action for agriculture was highlighted in the Global Commission on Adaptation's 2019 report *Adapt Now: A Global Call for Leadership on Climate Change Adaptation*, which urged "a large-scale, international mobilization over the coming decade to deliver improved incomes, ecologically sustainable food systems, and resilience for 300 million small-scale food producers" (Bapna et al. 2019, 60).

The challenge before the global community to build resilience and improve food security is profound. Even without accounting for climate change impacts on agriculture, the global "food gap," i.e., the difference between the amount of food produced and the amount necessary to meet likely demand by 2050, has been estimated at 56 percent more than what was produced in 2010 (Searchinger et al. 2018). At the same time, unanticipated crises like the COVID-19 pandemic can further undermine food security.

Climate change is further exacerbating the food security gap: Globally, the agricultural sector already accounts for an average of 26 percent of the total damage and losses from climate-related disasters (FAO 2017). This does not include slow-onset events, which the United Nations Framework Convention on Climate Change (UNFCCC) describes as including sea level rise, increasing temperatures, ocean acidification, glacial retreat and related impacts, salinization, land and forest degradation, loss of biodiversity, and desertification (UNFCCC 2019).

Beyond 2030, the negative impacts of climate change on the productivity of crops, livestock, fisheries, and forestry will become increasingly severe in all regions of the world (Gourdji et al. 2013; IPCC 2014). Global agricultural yields may decline by up to 30 percent by 2050 in the absence of ambitious climate action (Porter et al. 2014). The world also faces an increasing "potential risk of multi-breadbasket failure" (Wallace-Wells 2019; Gaupp et al. 2019), undermining our ability to cover regional food deficits through shifting global markets.

In part due to greater climate variability and more extreme weather events, global hunger is rising again after a decade of decline, with nearly 60 million more undernourished people than in 2014—an increase in the global prevalence of undernutrition from 8.6 to 8.9 percent of the world's population (FAO 2020a). Hunger and malnutrition are projected to increase further, by up to 20 percent by 2050, even if warming is kept to 1.5 degrees Celsius (°C) (IPCC 2014). Farmers, pastoralists, and other rural people make up a large proportion of the 120 million people that climate change puts at risk of falling below the poverty line by 2030 (Alston 2019).

In addition to climate change's direct impacts on agricultural production, it is linked with conflict, another key threat to food security for people living in poverty. For example, Hsiang and Cane (2011) demonstrated that the probability of new civil conflicts arising throughout the tropics doubles during El Niño years relative to La Niña years, while Hendrix and Salehyan (2012) analyzed over 6,000 instances of social conflict in Africa over 20 years to determine that rainfall variability has a marked effect on both large-scale and smaller-scale instances of political conflict. Impacts on food supplies are often the trigger; Iceland (2017) and Gleick and Iceland (2018) found that climate change impacts on water in relation to agriculture are often at the heart of such conflicts. The 2015 U.S. National Security Strategy notes that climate change is an urgent and growing threat, contributing to increased natural disasters, refugee flows, and conflicts over basic resources such as food and water.

Migration and internal displacement are outcomes of food insecurity, which is becoming more prevalent as climate change impacts intensify and is likely to increase in low-income countries that depend heavily on agriculture (FAO 2017). While the decision to migrate (and when) should be an adaptive choice for rural households, it is already a necessity in some areas where climate change impacts have made maintaining any type of agricultural production nearly impossible; small producers may have little choice but to forfeit their land and migrate to other areas (typically cities). These same conditions affect many other people whose livelihoods depend on agricultural value chains; for example, harvesting often relies on landless migrant laborers, and women frequently form the majority of workers in packaging and processing plants. Indian farmers from Uttarakhand and Maharashtra have migrated to regional cities due in part to devastating floods and chronic droughts, respectively, which have made their existing agricultural livelihoods impossible (Lal 2016). Similarly, increased numbers of Central American farmers attempting to cross the Mexican–U.S. border illustrate the beginning stages of the World Bank's estimate of around 2 million people being displaced from Central America by the year 2050 due to factors related to climate change (World Bank 2018).

Transformative adaptation for agriculture—which the authors define as promoting long-term resilience by continually shifting the geographical locations where specific types of crops and livestock are produced, aligning agricultural production with changing landscapes and ecosystems, and/or introducing resilience-building production methods and technologies across value chains—can provide the opportunity to improve livelihoods and create jobs. For example, some high-elevation areas may experience higher productivity or become warm enough to shift to higher-value crops. This is the case with coffee production in areas where it can be shifted up mountainsides (Moat et al. 2017). However, seizing such opportunities requires recognizing in advance how climate change will affect crop and livestock suitability and ensuring that farmers can access the knowledge, technologies, and inputs, as well as credit and markets, required to produce new types of agricultural products. However, shifting suitability can also raise the temptation for farmers and herders to encroach into areas like forested mountaintops that are rich in biodiversity, essential for maintaining vibrant watersheds and other ecosystem services, and vital for carbon sequestration. Such emerging threats must also be better anticipated and integrated into transformative adaptation plans and policies.

The world is beginning to respond to the dire projections of how climate change stands to undermine global food security. Dozens of countries are developing national adaptation plans (NAPs), which generally reflect the countries' largest economic sectors and highest priorities. Agriculture is often central in these plans. Additionally, more than 90 percent of current nationally determined contributions (NDCs) mention agriculture in some way (such as needs for support, inclusion in an economy-wide target, or specific policies and actions that address agriculture mitigation and/or adaptation). The existing NDCs of 131 countries (out of 189 total) include agricultural adaptation policies and measures—the vast majority of which emphasize crops and livestock, including water management and irrigation (Ross et al. 2019). And countries are increasingly recognizing that the planned 2020 NDC updates offer an opportunity to be more explicit about the transformations they

intend to achieve, what it will take to get there equitably and sustainably, and what assistance will be needed (Ross et al. 2019). Research organizations are also stepping up their efforts to expand understanding of where agricultural adaptation measures are most needed and which are proving most effective in various contexts (see, for example, Thornton et al. 2019 and De Pinto et al. 2019).

Despite progress on the policy and planning fronts, adaptation funding amounts to only 5 percent of tracked climate finance data (Buchner et al. 2019) and continues to fall short of the $1.8 trillion projected annual cost from 2020 to 2030 (UNEP 2018). An estimated $7.8 billion out of $30 billion in adaptation finance was allocated to the agriculture, forestry, land use, and natural resource management sector (Buchner et al. 2019). The water and wastewater management sector alone received more funding ($9.9 billion). Given the magnitude of the agricultural adaptation challenge, the amount allocated to this sector needs to increase. The agriculture sector forms the economic backbone of many developing countries; safeguarding it from climate change impacts is essential to reducing poverty and ultimately driving wider economic growth. This section explores how expanding adaptation action to include transformative approaches could build momentum for additional investments.

Evidence is emerging from the literature discussed below that even full implementation of common approaches to agricultural adaptation, such as breeding more resilient varieties of crops and livestock, improving seasonal forecasts and early warning systems, and expanding insurance for farmers and herders, may prove insufficient to address the challenges that lie ahead. New approaches to agricultural adaptation—such as transformative adaptation—are needed to complement the scaling of more conventional incremental measures. Transformative adaptation helps to avert and minimize loss and damage while enhancing global food security; reducing escalating risks of displacement, conflict, and crisis; and avoiding maladaptation. To enact transformative approaches to building climate resilience, adaptation policymakers, funders, and practitioners will need to shift their fundamental understanding of adaptation, and how it can transition systems and the societies they operate in (Pelling 2011; Pelling et al. 2014).

1.1 Attributes of Transformative Adaptation

Research organizations and adaptation funding entities have divergent perspectives on what transformative adaptation entails; this ambiguity has hindered progress toward identifying common goals and best practices. Therefore, the initial Transforming Agriculture for Climate Resilience (TACR) framework (Carter et al. 2018) offered an actionable definition (now refined) of what transformative adaptation for food systems entails, which, if widely adopted, could remove some of the lack of clarity that may be limiting progress:

Intentional alterations intended to build resilience in response to or anticipation of climate change impacts that are at such scale and significance and over a long enough time span that they change fundamental aspects of food systems.

The TACR framework first established three key attributes, which have evolved slightly from the original (Carter et al. 2018), that the authors hypothesize will often be included in agricultural adaptation plans, policies, funding proposals, and projects with high potential to be truly transformative:

- Shifting the geographical locations where specific types of crops and livestock are produced, processed, and marketed (growing more resilient varieties of the same types of crops and livestock would not require fundamental, systemic change, and is thus not considered transformative)
- Aligning agricultural production with changing ecosystems and available water and arable land resources—for example, shifting from irrigated crops to grazing when humid tropics transition to semi-arid grasslands after wildfires; or shifting from cropping to aquaculture in anticipation of or response to sea level rise
- Applying new methodologies and technologies that substantially change the types of agricultural products, or the way existing ones

are produced and processed, within a particular region or production system; for example, producing cheese instead of fresh milk to reduce the risk of spoilage in warmer conditions

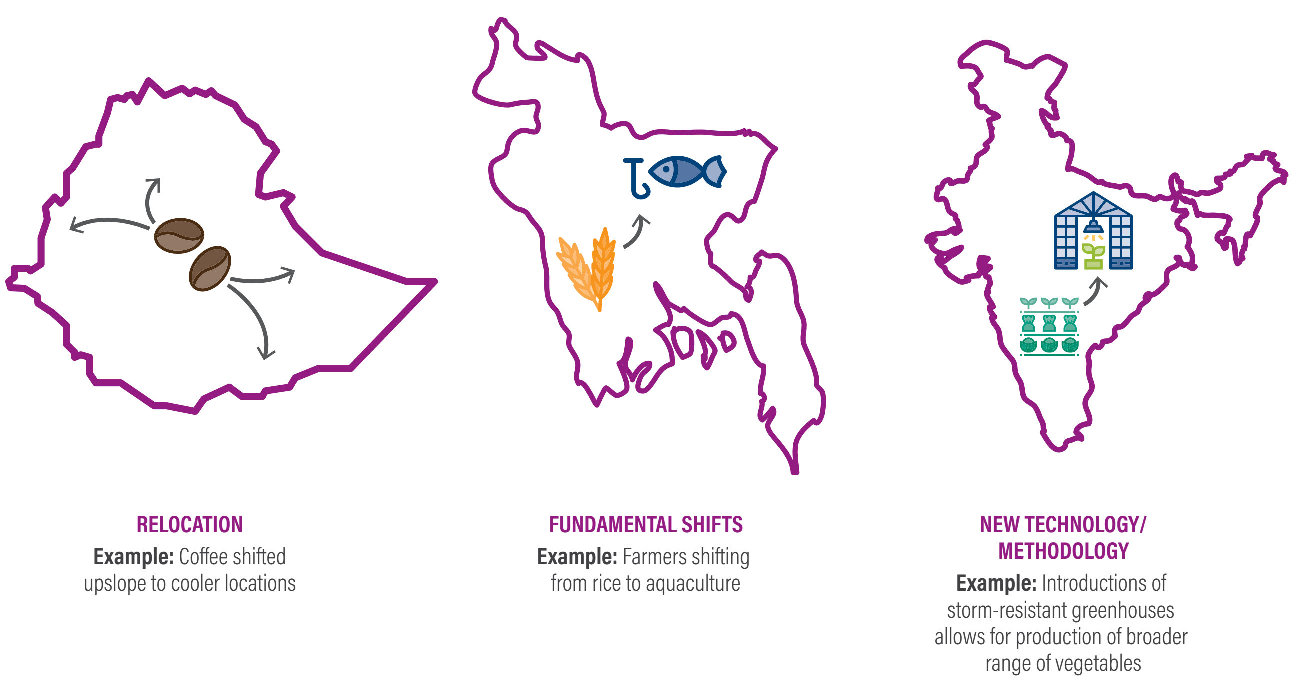
An example of each of these attributes is illustrated in Figure 1.

After describing why transformative adaptation in food systems is needed, this report delves into the benefits that this approach can provide. It details how fundamental changes to food systems can be incorporated into research agendas, long-term planning, financing, and implementation of adaptation measures. It calls for researchers and decision-makers to explicitly consider gender and social equity issues so that solutions serve the needs of those most vulnerable to climate changes—those who often have the least capacity to adapt and are most at risk from further consolidation of wealth and power. It concludes with calls to action to adaptation funding entities, governments, and research organizations to take up the charge of incorporating transformative approaches into their efforts to assist farmers and other rural people to build sustainable, equitable, inclusive climate resilience.

1.2 Methodology

The TACR project began with an extensive review of published academic literature on agricultural transformation and adaptation using keyword searches that focused on adaptation, resilience, transformation, system shifts, and/or long-term planning. Analyses were completed to determine the following: how academics and other agricultural researchers are addressing agricultural transformation and adaptation via literature review and expert consultations; whether and how the 21 most significant bilateral and multilateral adaptation funding entities are approaching transformative adaptation via review of their strategy documents and websites; and whether and how countries are addressing long-term, systemic adaptation in agriculture in their NAPs, NDCs, and submissions to the UNFCCC Koronivia Joint Work on Agriculture using Climate Watch and NAP Central.

Figure 1 | Examples of Attributes of Transformative Adaptation in Ethiopia, Bangladesh and India (from left to right)



Source: Authors.

Expert consultations with the working paper's primary audiences (adaptation funding entities, planners and policymakers, researchers, and implementing agencies) and with government officials and technical experts in Ethiopia and India helped in identifying case studies of existing systemic shifts in food systems to build long-term resilience. Interviews and meetings were convened with experts in agricultural adaptation from state and national government agencies in Ethiopia and India and agricultural research organizations in both locations. These included both countries' national research institutes and those affiliated with the Consultative Group on International Agricultural Research (CGIAR), including the International Livestock Research Institute, International Water Management Institute, and International Food Policy Research Institute (IFPRI). Group discussions took place in Ethiopia with staff from the local branches of organizations including the World Food Programme, the Food and Agriculture Organization (FAO) of the United Nations, and the Ethiopian Agricultural Transformation Agency. In India, the authors conducted a workshop, organized by the state Environmental Planning and Coordination Organization, with agricultural stakeholders in Madhya Pradesh. The research was also enriched through the authors' participation in panel discussions and workshops at UNFCCC events such as the 22nd and 23rd annual Conferences of the Parties (COPs), Intersessional meetings, and NAP Expos; the FAO's World Summit on Food Security; the CGIAR's 5th Global Science Conference on Climate-Smart Agriculture; the 2018 Adaptation Futures conference; and others. Input from adaptation funding entities was gathered on an ad hoc basis over the course of the research and through a roundtable discussion the authors convened during the 2019 UNFCCC Intersessional. Please note that consultations with the organizations mentioned above do not constitute their endorsement of the research and ideas contained in this report, which are those of the authors alone.

This preliminary research led to publication of a framework—*Transforming Agriculture for Climate Resilience: A Framework for Systemic Change* (Carter et al. 2018)—which established a workable definition for transformative adaptation in agriculture based on the Intergovernmental Panel on Climate Change (IPCC) definition mentioned in the Executive Summary.

This framework was then applied in three working papers on key agricultural topics: crop research and development (Niles et al. 2020), livestock production (Salman et al. 2018), and climate services (Ashley et al. 2020). Each of these papers started with its own detailed and technical review of relevant literature on each topic. Researchers also analyzed whether and how these topics were mentioned in NDCs or NAPs, and whether the relevant text included the elements of transformative adaptation established in the framework paper (Carter et al. 2018). Based on an assessment of the state of adaptation action in each topical area, researchers then identified gaps and challenges that hindered progress on transformative adaptation. Each of the papers recommended actions that the three key audience groups (researchers, governments, and adaptation funding entities) could take to encourage more widespread application of transformative approaches to adaptation.

World Resources Institute (WRI) researchers have also applied the TACR framework to coffee production in Costa Rica (Tye and Grinspan 2020) and tested against locally led climate-driven transformations (Ferdinand et al. 2020). With each application of the framework to these various topics and case studies, the researchers' thinking evolved regarding what constituted transformative adaptation and how it could be enhanced and more widely applied to build the long-term resilience of locations nearing tipping points for diminishing productivity of key agricultural products.

This final synthesis report both summarizes previous research and includes additional analysis of the limitations of incremental adaptation measures to global staple crops and the need to continually align crop and livestock production with changing ecological conditions. It assesses the potential for this approach to provide a broader range of benefits, including averting and minimizing economic and non-economic losses and damages as defined by the UNFCCC. It also includes an economic model that WRI researchers constructed and applied to a hypothetical shift from coffee to vanilla production in the highlands of Ethiopia to determine when transformative approaches make more economic sense than employing only incremental changes. The methodology used is detailed in Appendix A.

CHAPTER 2

INCREMENTAL ADAPTATION ALONE WILL LEAVE THE WORLD HUNGRY

This section examines available evidence to establish why transformative approaches to adaptation are needed to avert or minimize looming food security challenges and explores a range of issues that are preventing transformative adaptation from being more widely implemented. It assesses how mounting ecosystem degradation will undermine the ability of farmers, fishers, and herders to rely on traditional ways of managing climate variability and other risks.

2.1 Shortfalls in Staple Crops Projected

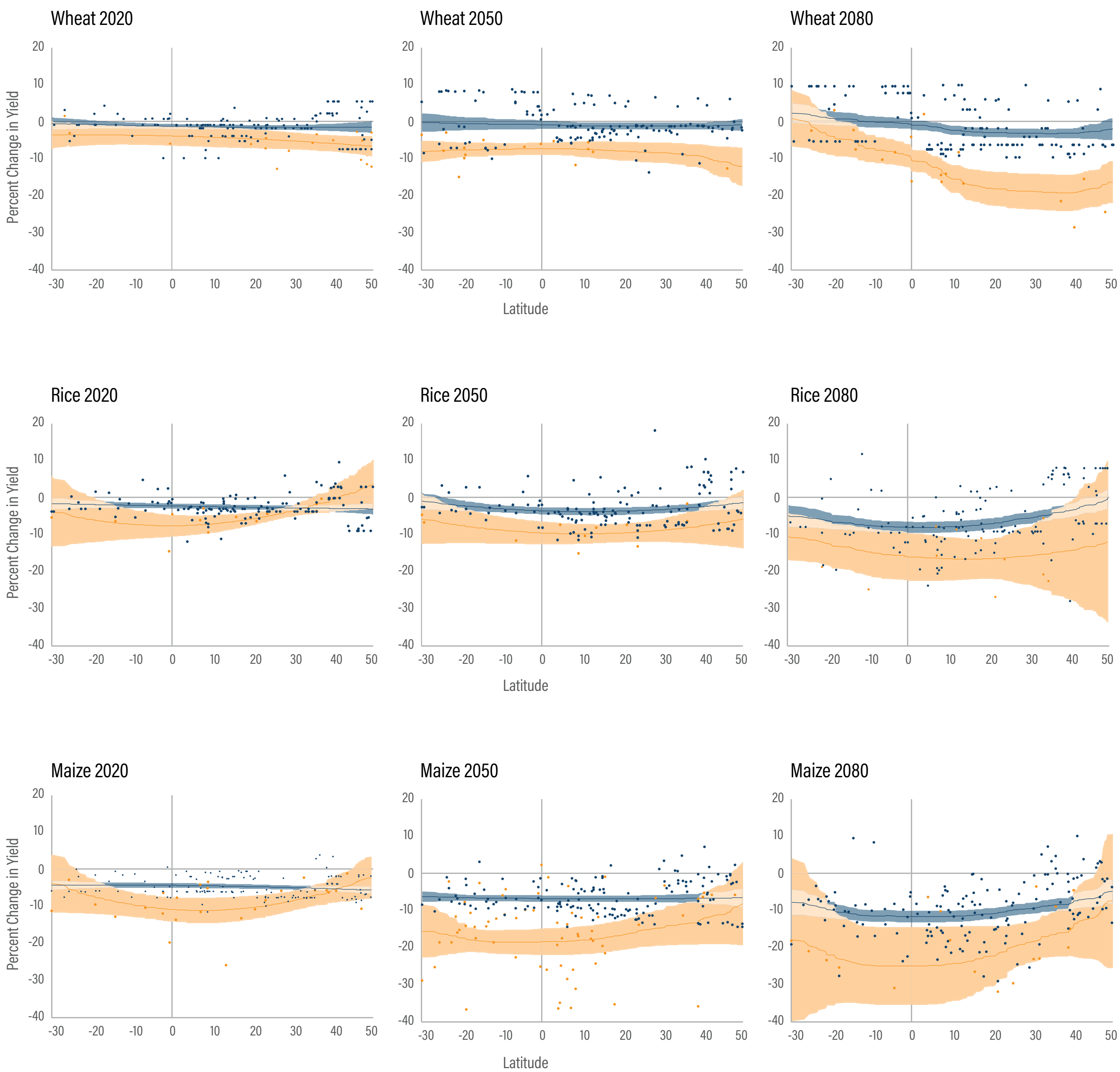
Recent analyses expose both the value of incremental adaptation measures in protecting the global food supply from climate change impacts, and also worrisome gaps between their likely effectiveness and the projected impacts of climate change on yields of staple crops. Figure 2 illustrates this point for the key global staple crops of wheat, rice, and maize. Based on a meta-analysis model of ~27,000 data points from studies published over the last four decades, Aggarwal et al. (2019) calculated variance around an ensemble mean of multiple studies of each particular crop, country, and time slice to illustrate projected percent changes in yield relative to a baseline of 1960–90 for 2020, 2050, and 2080. The orange and blue bands indicate a 95 percent confidence interval based on a thousand replications of the model. **The orange bands illustrate** the reference case of average modeled climate change impacts on these crops globally **without adaptation. The blue bands represent** average modeled impacts of climate change globally on these three crops over the coming decade **with incremental adaptation measures**. Each blue dot represents the blue band disaggregated to show individual countries.

Although the blue bands in the 2020 graphs are near the 1960–90 baseline for wheat and slightly under for rice and maize, the model predicts that yields of rice and maize could fall over 30 percent over the coming decades without adaptation (orange bands), and by a global average of up to 10 percent with adaptation (blue bands). However, while overall global declines are expected to be fairly minor with adaptation, some individual countries (depicted by the blue dots) fall well below the baseline and can expect to experience significantly declining yields of these staples even as their populations expand. These are countries where transformative adaptation is likely to be needed, while incremental adaptation may be sufficient in those with less dramatic declines. The graphs include latitude along the *x*-axis, making it clear that wealthy countries further from the equator will fare better than developing countries in the tropics, which are more likely to reach the limits of incremental adaptation sooner.

Despite this and other emerging evidence regarding the limitations of incremental adaptation measures, the vast majority of agricultural adaptation—including climate-smart agriculture (CSA) as it is commonly practiced—focuses on such measures. The intention of such efforts is to preserve existing food systems by building resilience to climate change impacts, rather than recognizing that more fundamental changes to what can be produced, where, and how will increasingly be needed. CSA projects rarely explore what will happen when incremental measures become insufficient to fully manage increasing climate risks. There is relatively little research available on how to respond when crops and livestock reach their physiological limits of how much additional heat or drought they can tolerate, sources of irrigation water are reduced by permanent drying trends or salinization from sea level rise, or marine species cannot be bred to handle dramatically increased ocean acidity. This is despite a growing body of research that indicates such limits are already being reached in some locations and contexts.

The evolving field of agroecology "seeks to optimize the interactions between plants, animals, humans and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system" (FAO n.d.). Agroecology and other types of nature-based solutions show great promise for advancing adaptation while reducing further losses in biodiversity and the unsustainable use of natural resources. However, relying exclusively on such approaches will grow increasingly risky as climate change impacts intensify. Projected shifts in global ecosystems will undermine a key assumption of agroecology: that ecosystems are stationary and stable and can thus be counted on to continue providing the same range of ecosystem services. When, for example, rainforests shift to grasslands, and grasslands shift to deserts, the amount of watershed regulation they provide will change, as will the interactions between wild pollinators and cultivated crops—both of which could undermine agricultural production. In addition, as Searchinger et al. (2018) suggest, there may be limited environmental contexts in which agroecology

Figure 2 | Average Impacts of Climate Change on Crop Yields, with and without Incremental Adaptation Measures, 2020, 2050, and 2080



Note: Based on a meta-analysis model of ~27,000 data points from studies published over the last four decades, Aggarwal et al. (2019) calculated variance around an ensemble mean of multiple studies of each particular crop, country, and time slice to illustrate projected percent changes in yield relative to a baseline of 1960–90 for 2020, 2050, and 2080. The orange and blue bands indicate a 95 percent confidence interval based on a thousand replications of the model. **The orange bands illustrate** the reference case of average modeled climate change impacts on these crops globally **without adaptation**. **The blue bands represent** average modeled impacts of climate change globally on these three crops over the coming decade **with incremental adaptation measures**. Each blue dot represents the blue band disaggregated to show individual countries.

Source: Reprinted from Aggarwal et al. (2019).

can contribute efficiently to meeting the concurrent goals of limiting global temperature increases and feeding a growing global population.

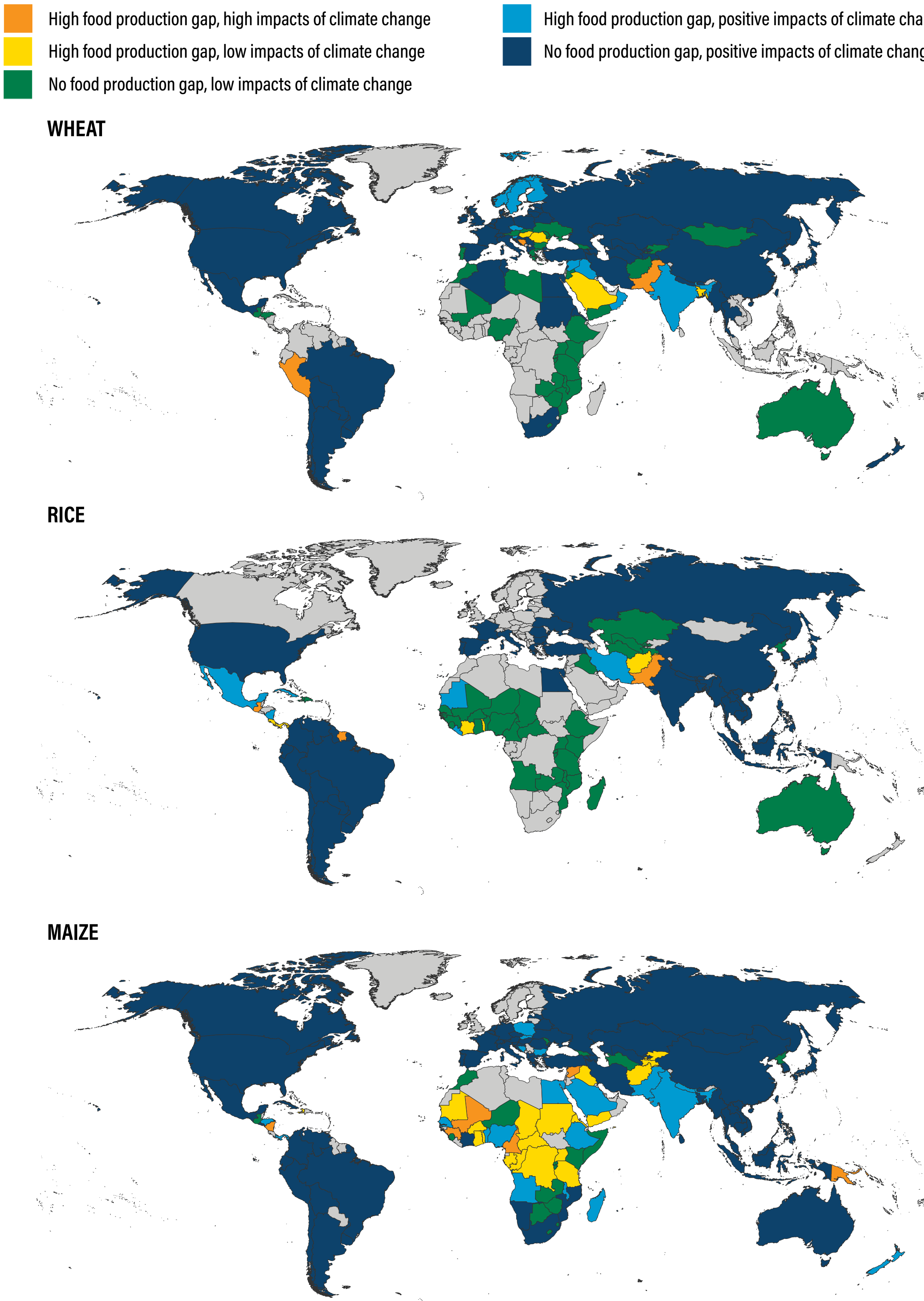
For similar reasons, although critically important, it should not be assumed that local knowledge and traditional solutions alone will be adequate to manage increasing climate-related agricultural risks. Such place-based expertise often evolved within fairly stable ranges of climate variability over generations. When those ranges shift beyond what traditional coping strategies can handle to unprecedented flooding or heatwaves, entirely new pests and diseases, or other novel challenges, traditional knowledge alone may not always suffice. Archaeological evidence suggests that climatic shifts contributed to the downfalls of the Maya civilization and those of the U.S. Southwest, to name just a few. Adaptation measures based on traditional knowledge should be recognized, valued, and considered along with less context-specific solutions—but not treated as silver bullets that can solve all climate-related challenges.

Local economies and markets will also have to respond to unprecedented circumstances. And while farmers are indeed often the best agents of change to influence other farmers—for example, the pioneer farmers referred to below when discussing autonomous transformations—they will need enhanced access to new types of crops and livestock and guidance on how to raise and market them.

As Figure 2 indicates, the limits to adaptation for agricultural crops will not be uniform across the globe. Looking more closely at maize, the third most important crop on the basis of harvested area, Ramirez-Cabral et al. (2017) found that under an A2 emissions scenario (i.e., at the higher end of emissions scenarios defined by the IPCC, but not the highest; see Nakicenovic and Swart 2000) for 2050 and 2100, tropical areas will experience the highest loss of climatic suitability, while regions closer to the poles will become more suitable. South America will have the greatest loss of climatic suitability, followed by Africa and Oceania, with large areas that are currently suitable for maize becoming limited by heat and dryness. On the other hand, Asia, Europe, and North America will become more suitable.

Figure 3 maps out hotspots where strong impacts of climate change are projected to lead to large gaps in wheat, maize, and rice production. The projections are based on assessments of impacts with adaptation on crop yield at the country scale for the 2050s and the food production gap (the difference between 2050 food demand and current food supply). Countries with high food gaps and high impacts of climate change are most vulnerable.

Figure 3 | Climate Change Hotspots



Source: Reprinted from Aggarwal et al. (2019).

A potential upside of this analysis may be that even countries projected to experience severe deficits in one or two of these staple crops—such as India, where both wheat and maize productivity are expected to decline—will often be able to continue producing similar amounts of other crops. For example, climate change impacts on rice in India are projected to be low, and it may be possible to grow more rice per hectare with improved varieties, inputs, and cultivation techniques, though this will be true only in locations where water supplies are adequate.

But a range of factors will impede farmers' ability to switch between crops. Some of these—e.g., soil type, seasonal microclimatic conditions, absence or presence of pests and pollinators—will be difficult to overcome. Others—such as access to information on how to grow new varieties; required inputs such as seeds, credit, processing facilities, and markets; and sociocultural factors such as consumer willingness to consume less traditional foods—become more possible to develop when the need for them is recognized in advance so they can be planned for, financed, and implemented; that is, where transformative approaches to adaptation can be applied.

2.2 Traditional and Cash Crop Yields Vital to Food Security Expected to Decline

In addition to these impacts on staple crops, those that are less important in global markets but are essential to food security are also likely to be severely affected; for example, a 43 percent decline in plantain yields in Central Africa is expected over the next 20 years (Fuller et al. 2018), while bananas and beans are also in jeopardy (Rippke et al. 2016). Traditional and wild crops hold potential for filling food security gaps, although they have been largely overlooked in climate change research (Niles et al. 2020). Wild crops include any seeds, roots, or leaves that can contribute to people's diets and are collected from uncultivated areas. Such crops are a significant portion of production in many low-income countries compared with the world's major staples. For example, in Niger, traditional crops (e.g., millet, cow pea, sorghum) are produced at a ratio of 46 to 1 (production, tonnes) compared with major world crops (e.g., maize, wheat, rice) (FAO 2020b; Varshney et al. 2012). These crops (e.g., bambara) are particularly important to women, who grow the majority of them, and smallholder farmers, who rely on them for food security (Oyugi et al. 2015). Other examples of traditional crops include amaranth, jute mallow, desert date, and Shona cabbage.

Furthermore, cash crops such as coffee are also at risk; declines in the production of cash crops will weaken the ability of those who depend on them to purchase food and thereby further undermine food security. More than 120 million smallholders rely on coffee for their livelihoods, but by 2050 climate change will threaten 50 percent of the area currently suitable for its production (Climate Institute 2016), meaning that the livelihoods of coffee farmers are in jeopardy. Although incremental adaptation measures such as improved varieties and better water and shade management can help, the crop is likely to meet the physiological limits of its heat tolerance as temperatures rise (Kath et al. 2020). Without transformative action

to adapt in areas where the crop is losing viability, such as by moving coffee production upslope to cooler areas and substituting crops that can thrive in warmer conditions, as explored in Section 3 of this report, the ramifications will be enormous.

2.3 Livestock Systems Are Also at Risk

As noted in the TACR paper on transformative adaptation for livestock production (Salman et al. 2019), climate change is also affecting the rapidly expanding livestock production sector, upon which an estimated one billion people living in poverty depend for food and income. An estimated 180 million people in developing countries depend on livestock grazing on drylands for their livelihoods (Thornton et al. 2008; Salman et al. 2019). Livestock production is particularly important in the semi-arid agroecological zones most at risk from climate change, some of which are growing too hot for current livestock breeds and facing desertification, which means that they will no longer be able to support current levels of grazing even if incremental solutions such as additional watering holes and improved forage are provided. As some of these hotspot areas lose viability for livestock production, herders' livelihoods will be threatened. The IPCC has linked climate change to lower animal growth rates in Africa (IPCC 2019), while the FAO projects global demand for livestock products to increase by 70 percent to feed a population estimated to reach 9.7 billion by 2050 (FAO 2019).

Livestock production systems around the world are already changing in response to demographics, markets, and economic development—but these transitions rarely consider long-term climate risks. Without the proper information and resources, livestock systems may not withstand intensifying direct and indirect climate impacts such as changing disease dynamics. Technical and financial support are needed to avoid excluding or disadvantaging those living in poverty and other vulnerable groups (Salman et al. 2019).

2.4 Some Regions, Landscapes, and Human Systems Are at Risk of Nearing Tipping Points

In a growing number of locations, current agricultural livelihoods may soon no longer be possible. These include the Mekong Delta, where salinization due to sea level rise threatens rice production; chronic drought in California, which threatens fruit and vegetable cultivation; and the creation of a dustbowl in East Anglia, England, due to drought and land degradation, which threatens homegrown vegetable production (Benton et al. 2017).

Particular regions and types of landscapes are likely to reach their adaptive limits sooner than others, especially over longer timeframes as the effects of slow-onset climate change impacts emerge. Figure 4 identifies types of ecosystems that are most vulnerable to water stress and other slow-onset events based on a review of available literature.

Figure 4 | Ecosystems Most Vulnerable to Water Stress and Other Slow-Onset Climate Change Impacts

SEMI-ARID AND ARID AGRICULTURE

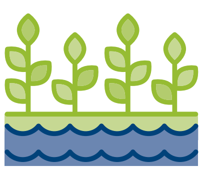
Tipping point: Decreased or unreliable water availability requires a transition from rainfed to irrigated agriculture or a transition to less water-dependent agricultural products

Example: Increasing aridity in northern Kenya severely impacts cattle herders, encouraging a switch to camel production

GLACIER- AND SNOWPACK-FED AGRICULTURE

Tipping point: Melting glaciers or snowpack decreases or eliminates water available for agriculture

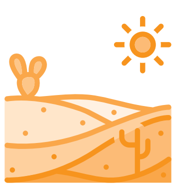
Example: Reduced glacial-melt water available for necessary irrigation in Peruvian highlands—what happens next is yet to be determined (see maladaptation example in Box 2)



COASTAL AGRICULTURE

Tipping point: Coastal agriculture is regularly or permanently inundated

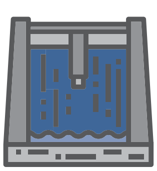
Example: Increasing frequency of coastal flooding (in conjunction with soil salinization) sparks transition from rice paddy to aquaculture in Bangladesh



AGRICULTURE IN DEGRADED WATERSHEDS

Tipping point: Landscapes already degraded by mismanagement and/or overpopulation are pushed beyond cultivation limits by climate impacts (e.g., increased temperatures, severe drought or flooding)

Example: Desertification of Mongolian rangelands due to overgrazing and increasing temperatures causes communities to introduce sylvopastoralism and new livelihoods (e.g., tourism)



AGRICULTURE IN WATER SYSTEMS WITH LONG-TERM MEGA INFRASTRUCTURE
(E.G., LARGE-SCALE DAMS, IRRIGATION CANALS)

Tipping point: Long-term mega infrastructure amplifies climate change impacts such that previous agricultural practices become nonviable

Example: Mega-dams in East Africa permanently alter critical seasonal agricultural flooding dynamics; in combination with increasingly unpredictable rainfall, historical agricultural practices become untenable, causing communities to relocate

Source: Authors.

National-level data can mask important limitations, such as the difficulty of shifting between crops in places with unsuitable precipitation patterns, inadequate water supplies, or inappropriate soil—not to mention the cultural and behavioral challenges of producing food that satisfies global markets or meets local preferences. The most damaging impacts of warming on rainfed maize, wheat, and rice have already been substantially moderated by shifting the locations where they are cultivated over time, along with expanding irrigation (Sloat et al. 2020). However, continued crop migration will be limited by socioeconomic and political factors, as well as land suitability and water resources, and care must be taken to prevent substantial environmental costs by pushing agriculture into uncultivated areas. Food production must be increased through sustainable intensification (i.e., higher yields per unit of land) rather than expanding crop or grazing land and converting forests, savannas, and peatlands to farmland. This will often require stronger legal protection for natural areas (Searchinger et al. 2018).

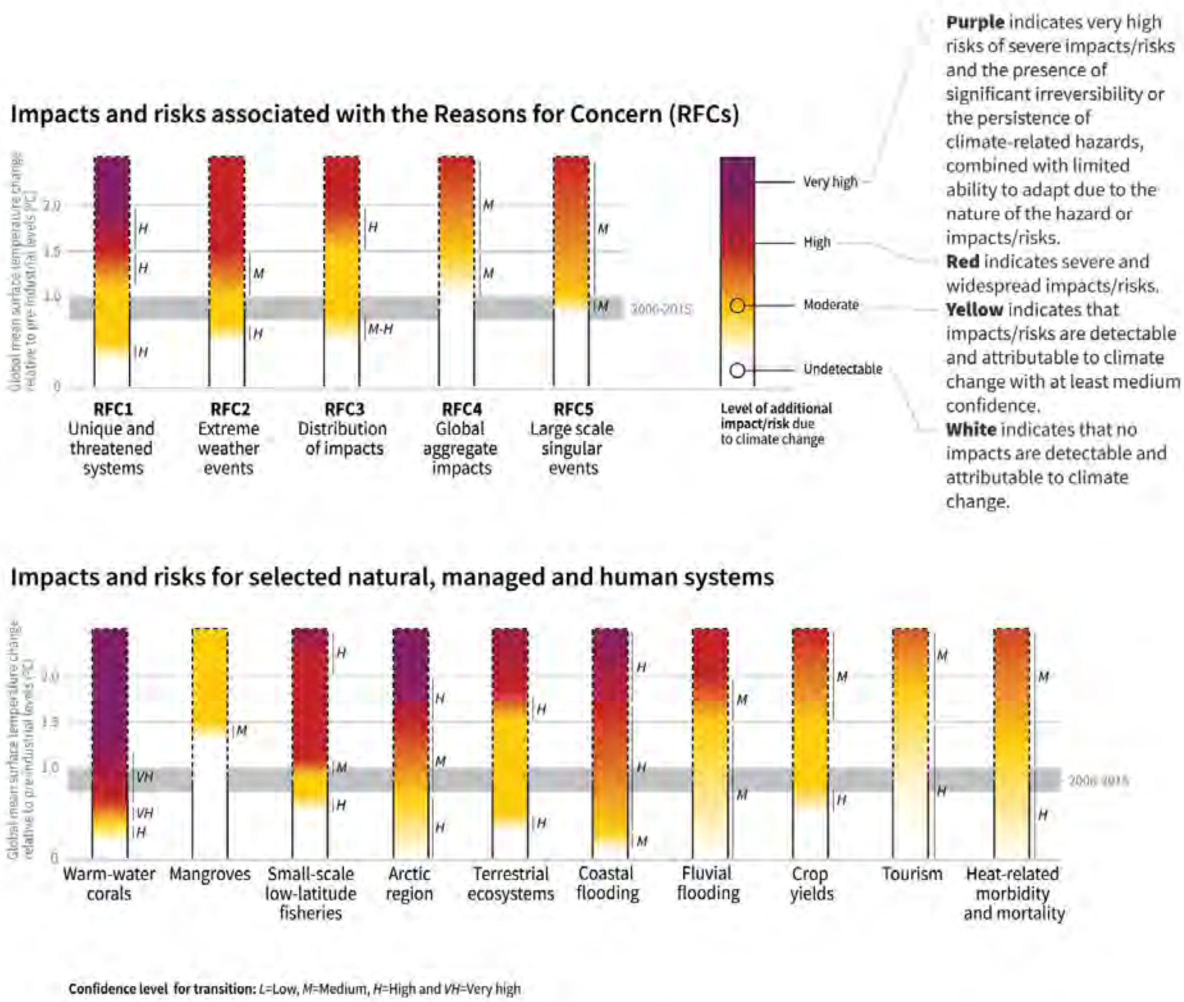
Such broad-scale projections may also gloss over the true impacts on social groups expected to be hardest hit, such as female-headed households, the poorest farmers, landless tenant farmers, and day laborers (Niles and Brown 2017; Niles and Salerno 2018).

According to the IPCC *Global Warming of 1.5°C* special report, in a growing number of places in the world, climate change is pushing systems—including ecological, but also agricultural, hydrological, economic, and others—toward severe and widespread risks (IPCC 2019). Figure 5, derived from that report, depicts the risks to natural, managed, and human systems around the world as temperatures rise.

As shown in Figure 5, crop yields, a central focus of this paper, are expected to experience moderate to high climate change impacts. Other primary systems required to maintain global agricultural productivity that are at risk as temperatures rise include terrestrial ecosystems and coastal and fluvial flooding; climate change impacts are projected to range from moderate to very high in these systems. The graphic also includes moderate to high impacts of rising temperatures on heat-related morbidity and mortality, which is critical to agricultural productivity; farmers will not be able to maintain productivity when more days become simply too hot for them to work in their fields or herd their animals. Note, however, that Figure 5 includes temperature increases only up to 2.5°C. A more recent review of all available evidence (Sherwood et al. 2020) finds that the odds of a temperature shift below 2 degrees is less than 5 percent under a high-emissions scenario (the world's current trajectory), while there is a 6 to 18 percent chance that temperatures will shift more than 4.5°C, or 8.1 degrees Fahrenheit. This estimate closely matches cumulative emissions over the past 15 years (Berwyn 2020). This would push critical systems toward tipping points beyond which changes would be irreversible and the limits of adaptation would be reached.

Other systems that humans depend on for food security, such as warm-water coral reefs and tropical freshwater fisheries, as well as coastal areas that are home to 10 percent of the world's population, are also subject to tipping points where severe, irreversible climate change impacts occur as temperatures rise and the limitations of adaptation are reached (IPCC 2019). Beyond these tipping points, these systems will no longer exist in the form they do today—including the food systems of an increasing number of places. This signals that fundamental, systemic transformations are needed.

Figure 5 | Impacts and Risks for Selected Natural, Managed, and Human Systems



Note: Crop yields, a central focus of this paper, are expected to experience moderate to high climate change impacts. Other primary systems required to maintain global agricultural productivity that are at risk as temperatures rise include terrestrial ecosystems and coastal and fluvial flooding; climate change impacts are projected to range from moderate to very high in these systems.

Source: Reprinted from IPCC (2019).

2.5 Entire Ecosystems Are Shifting; Food Systems Must Shift Along with Them

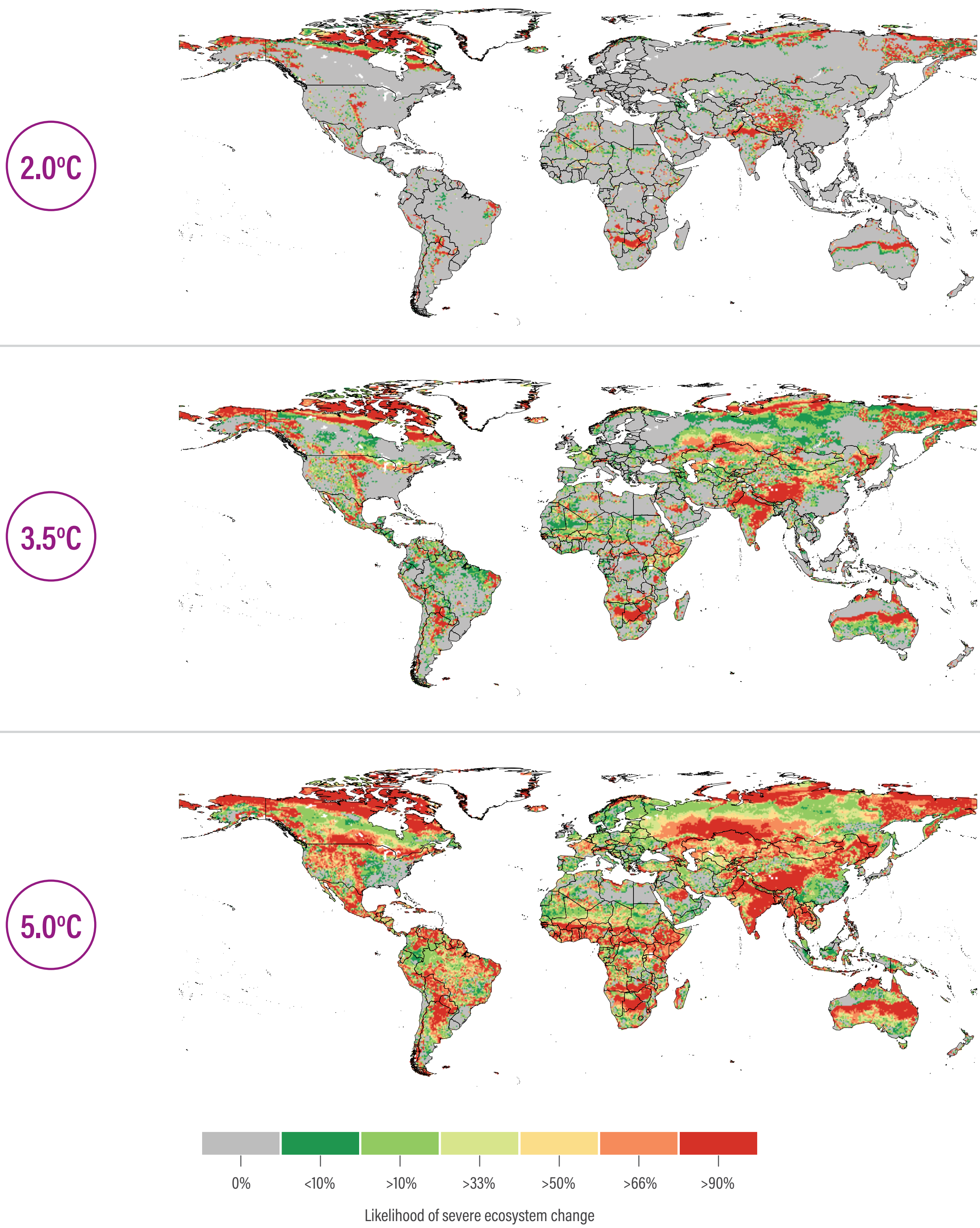
The projected impacts of climate change will lead to dramatic, ongoing changes in the plants and animals found in a particular area, comprising shifts of entire ecozones. For example, some recent climate change–linked fires in the Amazon rainforest are expected to result in permanent conversion to grasslands (Cooper et al. 2020), semi-arid areas are becoming deserts in regions like the Sahel (Huang et al. 2016), sea level rise is eating away at coastlines in West Africa (Croitoru et al. 2019), and groundwater aquifers are becoming too salty to be used for irrigation or drinking water in the Nile Delta (Abd-Elhamid et al. 2016).

Figure 6 depicts the magnitude to which global terrestrial ecosystems are expected to change as planetary warming continues. It illustrates that, while severe ecosystem changes (in red) are largely limited to Arctic areas with 2°C warming, they will become far more widespread and affect more populous areas with 3.5°C warming. Most of the planet's ecosystems will be severely affected and no longer function as they currently do if 5°C of warming is reached.

Recent analysis (IE&P 2020) finds that approximately one billion people live in countries that lack the resilience to manage the ecological changes they are expected to face between now and 2050. Of the 157 countries covered by this analysis's Ecological Threat Register, 22 percent will face catastrophic food insecurity—that is, they are likely to experience a substantial increase in undernourishment—by 2050. Without swift and substantial action, this could also result in unprecedented displacement of people.

Regions that experience a mean annual temperature of over 29°C are projected to expand from 0.8 percent of the world's surface to 19 percent. Such areas are currently largely concentrated in the Sahara and affect relatively small numbers of people, but are expected to grow to encompass areas inhabited by one-third of the global population. This is in contrast to a projected shrinking of zones with mean annual temperatures of approximately 11–15°C, where most current production of crops and livestock largely takes place (Xu et al. 2020) and could therefore be considered

Figure 6 | Likelihood of a Severe Change in Ecosystems



Notes: Abbreviation: °C: degrees Celsius. While severe ecosystem changes (shown in red) are largely limited to Arctic areas with 2°C warming, they will become far more widespread and affect more populous areas with 3.5°C warming. Most of the planet's ecosystems will be severely affected and no longer function as they currently do if 5°C of warming is reached.

Source: Reprinted from Gerten et al. (2013).

the most suitable temperature range. Under a business-as-usual climate change scenario, the geographical position of this temperature niche is projected to shift more over the coming 50 years than it has since 6000 BP (before present). The regions that will be most affected are among the poorest in the world—and thus our efforts at finding and applying new approaches to adaptation will be most needed in these areas.

As climate change risks affect many types of ecosystems simultaneously, essential connections between agricultural production and natural systems will be impacted in ways that are likely to undermine the ecosystem services farmers depend on, such as regulating water supplies or supporting pollinators. For example, pollinators such as birds, bees, and butterflies are essential for the production of 35 percent of the world's crops (Abrol 2012). Yet the variety of wild pollinators essential to crop production is falling due to climate change impacts (Giannini et al. 2017). New pests and diseases are already spreading into areas unaccustomed to coping with them. This may overwhelm local knowledge and capacity to deal with outbreaks by using traditional, non-chemical measures, as was the case with the recent locust plague in East Africa. Such changes may also affect rural households by jeopardizing the forest products they depend on, and increase the risks of wildfires, landslides, and other impacts.

Food system transformations should occur in alignment with ecosystem shifts to improve resilience and make more possible the sustainable use of water, land, and energy. While it may be possible, for example, to grow lettuce in the desert Southwest of the United States and tomatoes in greenhouses in arid northern Mexico, this can be accomplished only with depletion of scarce ground water for irrigation and heavy infusions of energy to cool greenhouses. This is an example of an unintended consequence of increasing the risk of maladaptation, which is addressed in greater detail in Section 4.2.

CHAPTER 3

ADAPTATION POLICY AND PLANNING RESPONSES ARE INADEQUATE

Despite the daunting challenges, few governments are identifying and addressing situations where climate impacts have already or will soon exceed the resilience that incremental measures provide.

A review of the agricultural adaptation components of available NAPs, NDCs, and Koronivia Joint Work on Agriculture documents revealed that most agricultural adaptation plans thus far have emphasized the rapid scaling of measures intended to preserve existing systems by building resilience over the short term; few include language indicating that they are planning for systemic shifts in anticipation of intensifying climate change impacts (see Figure 7).

Exceptions include Bolivia's prioritization in its NDC of a "transition to semi-intensive systems of livestock management and integrated management of agroforestry and silviculture techniques," (PSB 2016) and Burkina Faso's mention in its NAP of "abandoning certain crops in favor of those which are more resistant to climate shocks" (MEFR 2015). In addition, Costa Rica's NAP recommends using a long-term perspective in planning and implementing interventions, and appears to be unique in that it defines transformative adaptation as follows:

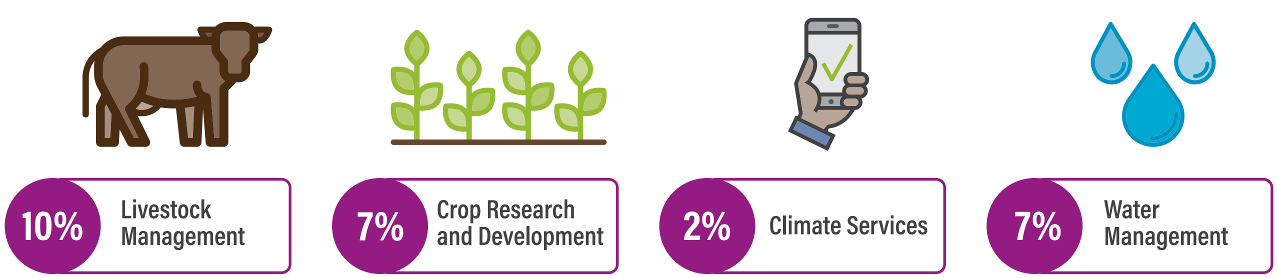
> *"**Transformation** implies a structural change in the institutional, cultural, technological, economic and ecological dimensions of a system to establish new development pathways. It must take shape through changes in productive systems, public investments, urban and territorial planning, to positively impact underlying risk factors and avoid eventual climate damages and losses (GCR 2018)."*

3.1 Lack of Clarity and Cohesion on What Transformation Entails

One reason for the dearth of language (and, consequently, action) regarding longer-term, systemic change may be a lack of common understanding about what transformation entails. The term "transformation" and its variants are currently being widely applied to adaptation with a range of meanings—often to indicate the need for "bigger, better adaptation," or more durable and equitable adaptation, but referencing only scaling up current adaptation practices rather than acknowledging that *fundamental* changes will be needed. A review of strategic documents from 21 of the largest adaptation funding entities, including multilateral and bilateral banks and donor agencies, finds that ambiguity around the meaning of "transformation" extends to their interpretations of transformative adaptation and its role in their portfolios of projects and programs varies considerably.

Another source of confusion about transformative adaptation is conflating it with agricultural transformation, which has been defined as a process that leads to higher productivity on farms, commercially orients farming, and strengthens the link between farming and other sectors of the economy (Boateng 2017). This form of transformation typically aligns with development goals but is not initiated with the intention of explicitly delivering climate resilience outcomes and may or may not achieve that goal.

Figure 7 | Key Areas of Agriculture in Nationally Determined Contributions that Reflect Transformative Adaptation



Sources: Livestock management (Salman et al. 2019); crop research and development (Niles et al. 2020); climate services (Ashley et al. 2020); water management (Authors).

3.2 Autonomous Transformative Adaptations Are Limited

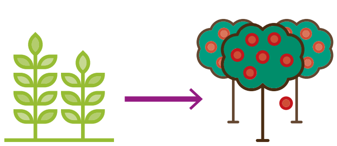
The handful of autonomous transformative adaptations that have taken place in response to climate change impacts without external planning or support are instructive in understanding what motivates and enables fundamental, systemic changes to food systems. Examples include the following:

- Borana herders in northern Kenya are shifting from cattle to camels in response to increasing heat and aridity (Salman et al. 2018; Kagunyu and Wanjohi 2014).
- Bangladeshi farmers in Bagerhat District have shifted from rice production to aquaculture in response to increased salinity due to saltwater inundation from the sea and reduced seasonal river flows (Faruque et al. 2016).
- In Costa Rica, some coffee farmers in areas that have grown too warm to continue producing coffee are switching to citrus (Ferdinand et al. 2020).
- In southeast Kazakhstan, increasingly scarce water supplies have been reallocated to less water intensive crops in response to reductions in snow cover and water supply with the intention of shifting the mix of crops grown in the region (Barrett et al. 2017).
- In Uttarakhand, India, mountain farming villages affected by increased rainfall variability are being abandoned and reverted to forest or pastureland while more people engage in intensive agriculture in river valleys or shift to nonagricultural livelihoods (IMI 2019).
- In Northeast India, dragon fruit has been successfully cultivated for the first time due to hotter and drier climate conditions (Thokchom et al. 2019).

Figure 8 illustrates additional examples from India of changes initiated by farmers that were not part of a specific national or subnational policy, program, or project. Box 1 provides a more detailed explanation of the process and outcomes for the switch in Himachal Pradesh.

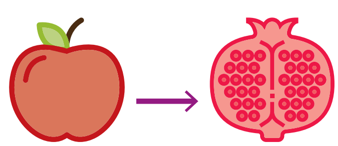
These types of transformations often take place gradually over years or even decades. They usually involve sequences of incremental actions of various types that together result in significantly different

Figure 8 | Examples of Autonomous Transformative Adaptation in India



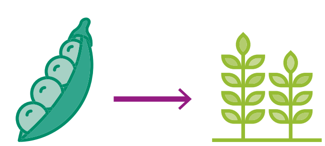
Rice Paddy to Orchards in the Srinagar Valley, Jammu/Kashmir

Variable rainfall and out-migration has driven a shift from rice to orchard fruit production (e.g., plums, apricots, etc.). Because of the switch there has been a measurable increase in river flow down the Jehlum River, which feeds the Brahmaputra River.



Apples to Pomegranates in the Kullu Valley, Himachal Pradesh

Increasing temperatures and a reduction in the number of chilling hours for apple cultivation has resulted in the replacement of apple by pomegranate.



Soybeans to Rice Paddy in Western Madhya Pradesh

Pest prevalence and falling prices has encouraged a switch from soybean to rice paddy cultivation. Short term gains may be eclipsed by long-term losses based on projected water availability in the region. This is an example of potential maladaptation.

Source: Authors.

growing locations or methods of production for crops and livestock, or even landscape-scale changes in the type of food system. Such transformations may have increased resilience to climate change as either the primary goal or as a side benefit; alternatively, they may in fact have increased vulnerability (i.e., maladaptation). Box 1 provides an example of a transformation that inadvertently—but fortunately—increased resilience in India.

BOX 1 | Case Study: Transformative Change from Apple Production toward More Diversified Production Schemes in Himachal Pradesh, India

A changing climate has contributed to decreased apple production in Himachal Pradesh, India, over the past 20 years, mostly due to warming winters, which have reduced the chilling hours required to produce high-quality apples. In response, farmers have diversified their crop production in low and mid-altitudes that are now marginal for producing apples. In these areas, farmers have started intercropping vegetables such as tomatoes, peas, cauliflower, broccoli, and cabbage in apple orchards, and cultivating "low chill" fruits such as pomegranates and kiwis.[a] At the same time, apple production is shifting into higher elevation areas that were previously too cold.

Farmers in Himachal Pradesh were able to transform agricultural production in response to climate change because of a series of events that began in the late 1950s (before climate change was explicitly considered), which steadily increased apple acreage in higher latitudes.[b] At that time, the government targeted India's Western Himalayan region with commercial horticulture programs to improve livelihoods. The Sino-Indian War at the border of India and Tibet led to significant infrastructure development, which improved agricultural market connections.[c] In 1971, the World Bank financed the establishment of the Himachal Pradesh Horticultural Produce Marketing and Processing Corporation to provide post-harvest facilities such as cold storage and packing centers.

Simultaneously, a network of localized crop research and development (R&D) institutions started expanding to assist farmers and the growing local horticulture sector with research, seeds, and advice, including the Central Potato Research Institute at Shimla; Directorate of Mushroom Research in Solan; Indian Agricultural Research Institute's Regional Research Station for Vegetable Research in Katrain (Kullu Valley); Institute of Himalayan Bioresource Technology in Palampur; and the University of Horticulture and Forestry in Solan.[d] Critical for adaptive capacity, the New Policy on Seed Development was implemented by the Indian government in 1988. A market intervention scheme was also developed to fix the prices of fruit crops and smooth harvest shocks.[e]

Although not intended to facilitate adaptation to climate change, the multisectoral development of market infrastructure and post-harvest facilities (which also reduce food loss and waste), an agricultural R&D network, and effective seed and pricing policies provided the enabling conditions for the farmers of Himachal Pradesh to move cultivation of apples to higher elevations and replace diminishing orchards with high-value vegetable and fruit production. Local land tenure arrangements wherein low-to-mid-latitude farmers own land in both lower and higher altitudes (known as *kanda*) also made it more possible to relocate crops when climate impacts made this beneficial. Active investment in civil society and empowerment of women, including the enforcement of political representation for women, welfare programs, and a culture of promoting women's self-interest, also facilitated transformation. Additionally, an active and supportive space for nongovernmental organizations has supported the implementation of significant projects in various sectors including agriculture.[f]

This transformation from an apple-dominated production system toward more diversified production was made possible by compounding strategies, projects, and programs over decades and with the involvement of government, farmers, and the private sector. Although the specifics will vary according to context, this case study demonstrates how the capacity for transformative adaptation can be built through investment in enabling conditions over the long term.

Notes: [a.] India Science Wire 2018; [b.] Basannagari and Kala 2013; [c.] Rahimzadeh 2017; [d.] Sharma 2011; [e.] Sharma 2011; [f.] Drèze and Sen 2002.

While these examples provide evidence that transformative adaptation is possible, simply waiting for such significant changes to take place organically is unlikely to enable those living in poverty and the most vulnerable farmers, including women and youth, to keep up with intensifying climate change impacts. Few individual farmers are able to identify and embrace such changes on their own, and many lack the resources needed to enact them. As noted in Ferdinand et al. (2020) and Tye and Grinspan (2020), research indicates that farmers who are able to make such changes without external assistance tend to be those with greater access to resources (e.g., land, credit, information, technical capacity), those with ways of reducing risk, and/or those who have a higher tolerance for risk.

In addition, systemic shifts require not only changing what farmers and herders themselves do, but also addressing other links in value chains, such as processing, marketing, and distribution, plus the availability of adequate inputs, labor, and credit, which are largely beyond the control of individuals. However, engaging pioneer farmers and herders and building on their experiences is essential to enabling more widespread, long-term, and systemic change to occur.

CHAPTER 4

TRANSFORMATIVE ADAPTATION TO BUILD CLIMATE RESILIENCE

As noted in Section 1, the TACR project hinges on the IPCC's definition of transformational adaptation (IPCC 2014, 839): *Intentional alterations intended to build resilience in response to or anticipation of climate change impacts that are at such scale and significance and over a long enough time span that they change fundamental aspects of food systems.*

In addition to helping to avoid the negative impacts described in Section 3, transformative approaches to adaptation can help address these challenges, and have the potential to provide a range of adaptation benefits including reducing the risk of maladaptation, averting and minimizing loss and damage, and providing economic, social, and environmental co-benefits.

4.1 Reducing the Risk of Maladaptation

Although increased funding and political will are ramping up the speed and scale of adaptation to climate change, greater foresight is required to ensure that today's adaptation investments will stand the test of time. Transformative approaches to agricultural adaptation can help avoid short-sighted investments that will lead to maladaptation; that is, actions that may lead to increased risk of adverse climate-related outcomes (IPCC 2019). The IPCC (2014) and Ericksen et al. (2021) note that maladaptation can arise from decisions that emphasize (or consider only) short-term outcomes, while a longer-term or more systemic perspective would reveal that the proposed intervention is in fact increasing climate risk, rather than lowering it. The risk of unintended negative consequences from technological adaptation interventions merits particular attention.

In fact, agricultural transformation has sometimes led to maladaptation, as a case study from Peru demonstrates (see Box 2). In this case, better understanding of climate change impacts on the water supply and, thus, the long-term viability of the irrigation system would have been helpful when decisions regarding initial investments were made. Funding might have instead been channeled to expand production of varieties of crops that were more suitable for the arid landscape or to support nonagricultural economic activities.

BOX 2 | Maladaptation in Water Management in Peru

With the intention to improve agriculture and livelihoods in the country's arid north, the Peruvian government began in 1985 an ambitious irrigation project to build a 50-mile canal to bring both irrigation water and electricity from a large hydroelectric plant to villages in the area of Chavimochic. Over the ensuing decades, the project has been expanded with funding from various multilateral development banks to add hundreds of thousands of irrigated acres and new jobs[a] and provide a water treatment plant that serves 70 percent of the local population, enabling Peru to triple its agricultural exports from $400 million to $1.2 billion.[b] The total cost of the project is estimated at $825 million.

By standard development measures, the project has admirably met its goals of reducing poverty and improving livelihoods: This area is one of the most economically competitive in the country, with better human development indices and higher average life expectancy and family income than those of many locations.[c] In addition, women from rural areas have reportedly benefited from more formal work opportunities, rural development, poverty reduction, improvement in purchasing power and prosperity, improvement in gross domestic product per capita in the region, and an increase in exports and foreign currency for the country.[d]

However, from a climate impacts perspective, the project is running on borrowed time. Glaciers, which provide about 7 percent of the water in this irrigation system on average and over half in times of severe drought,[e] are shrinking quickly—by 40 percent since 1970 and up to 30 feet per year more recently.[f] Not only is agriculture threatened, so are the livelihoods of 50,000 people who receive electricity from the hydroelectric plant, and 700,000 who consume treated river water.[g] The threat of conflict is also growing, as drainage and pesticide runoff raise pollution and salinity levels, making farmlands unfit for cultivation.[h] New approaches to water management are urgently needed because, despite widespread evidence of highly sophisticated Andean adaptations to variability in water availability, climate change "may be so rapid that traditional agricultural and water management practices are no longer useful."[i]

Although this case study is specific to Peru, it is just one example of how decisions based on existing data and focused on providing an immediate solution (without considering long-term impacts) are being replicated in many ways and contexts across the world. Only time will tell how much of the current spending on adaptation measures will ultimately prove maladaptive—but longer-term planning for systemic change offers the best chance of reducing risk and ensuring that investments will stand the test of time by reducing intensifying climate risks, so that they can continue to be beneficial.

Notes: a. Schmall 2010; b. CAF 2013; c. Amaro 2017. d. Amaro 2017; e. Buytaert et al. 2017; f. Casey 2017; g. Casey 2017; h. Lynch 2015; i. Lynch 2015.

4.2 Averting and Minimizing Loss and Damage

In addition to reducing maladaptation, transformative approaches to adaptation offer great potential for shaping a comprehensive, inclusive, and strategic approach for averting and minimizing loss and damage; that is, impacts of climate change that have not been or cannot be avoided through mitigation and adaptation efforts (Van der Geest and Warner 2015). Examples could include sea level rise that is too severe to be stopped by sea walls, mangroves, or other solutions, or permanent desertification of savannah areas. The Warsaw International Mechanism for Loss & Damage associated with Climate Change Impacts (WIM), which was created by the UNFCCC at COP16, has engaged Parties to the Paris Agreement in exploring responses to extreme and slow-onset events, and includes transformative adaptation (UNFCCC 2011) in the WIM Executive Committee's work plan.

Transformative approaches to adaptation can minimize or avert loss and damage by improving economic outcomes over other adaptation approaches, as the case study in Box 3 illustrates. It models a case study on the potential economic benefits of three possible approaches to managing risk and mitigating loss and damage due to the decreasing productivity of arabica coffee in regions of Ethiopia that are growing too warm for it. Three scenarios are tested, one of which results in significant losses to livelihoods; a second in which such damages are minimized; and a third in which losses are averted by taking a transformative approach to planning for future coffee production.

4.3 Improving Investment Strategies

Scaling up incremental agricultural adaptation interventions, such as mulching, small-scale irrigation, and water harvesting, may seem both more affordable and manageable for individual farmers, and appear to make the most economic sense. However, in circumstances where climate change impacts will be so severe that such measures will eventually prove insufficient, continual investment with short-term planning horizons may in fact cost more over time and do little to avert or minimize permanent losses and damages.

Box 3 shares the results of an economic analysis undertaken for this project. It compares the economic outcomes of three adaptation scenarios: no action, incremental, and transformative.

BOX 3 | Economic Modeling of Climate Change-Induced Shifts in Ethiopian Coffee Production

Intensifying droughts and increased variability of rainfall threaten the livelihoods of 15 million people in Ethiopia who directly or indirectly rely on coffee production, the majority of whom are smallholder coffee farmers.[a] It is estimated that per-hectare productivity of existing coffee systems will decline due to rising temperatures,[b] and 39–59 percent of current coffee farms in Ethiopia will become unsuitable for coffee production by 2050.[c] This will also affect the 25 percent of the country's export earnings that are attributed to coffee production.[d]

The following illustrative economic analysis assessed three scenarios designed to compare economic outcomes of different adaptation pathways going out to 2050:

- **Scenario 1: A no-action scenario** in which no adaptation action occurs. Arabica coffee production declines due to higher temperatures. This scenario serves as a baseline for estimating the economic losses due to climate change impacts.
- **Scenario 2: An incremental adaptation scenario** in which coffee farmers whose land becomes too warm to continue producing arabica coffee replace it with more heat-tolerant robusta coffee. Ethiopia has yet to enter the robusta coffee market, in large part because of the variety's much lower market prices. However, switching to robusta coffee[e] could help farmers maintain high coffee productivity without fundamentally changing inputs or cultivation practices. This option was chosen as the incremental scenario over other potential actions such as adding irrigation, shade trees, or mulching in cultivation practices so that the current production system would be maintained (and due to a lack of analyzable data on the costs of such measures).
- **Scenario 3: A transformative adaptation scenario** in which areas that become unsuitable for arabica production are fundamentally changed by replacing coffee with an alternative high-value perennial cash crop—in this case, vanilla. Vanilla was selected as it has been cited as a potential alternative to coffee production that would provide equal or higher economic value.[f] In this scenario, vanilla is produced in shade houses that can control for humidity, which is a limiting factor in some regions of Ethiopia. However, vanilla trial plots in Ethiopia were found to be adaptable to all trial locations with comparable yields and quality.[g] Other potential coffee alternatives not analyzed in this case study but that could be used in a similar economic analysis include cocoa, macadamia nuts, and spices (cardamom, cinnamon, and nutmeg).[h,3] The objective of this scenario is not to analyze the commodity or suggest that farmers switch to it, but instead to enable a comparison between incremental versus transformative approaches.

Temperature increases are expected to remain within the optimal ranges for growing robusta coffee and vanilla for several decades. Benefits and costs were estimated for the three future adaptation scenarios for a period of 35 years between 2015 and 2050, which enabled comparison of the costs of Scenario 1, the no adaptation baseline, with the respective economic gains of Scenario 2, incremental adaptation, and Scenario 3, transformative adaptation (see Table B3.1).

Two potential temperature increase scenarios were considered in the baseline scenario (Scenario 1) to account for uncertainty regarding how much and how quickly temperatures will rise and how this will affect arabica coffee production in the future. Our analysis suggests that, **with no adaptation measures (as illustrated in Scenario 1), local coffee farmers are expected to face a collective permanent loss of $208–256 million (measured at a discount rate of 6 percent) between 2015 and 2050 due to climate change impacts on arabica production**.

However, **if coffee farmers moved toward an incremental adaptation trajectory (Scenario 2)**, in which a large-scale conversion from arabica to robusta coffee would occur in production areas that are no longer suitable for arabica, **farmers could generate moderate net economic gains of up to $115 million by 2050 (compared with baseline Scenario 1)**, after deducting the adaptation costs (US$2.3 billion). These costs include those for labor and materials necessary to establish and maintain the robusta coffee production system during a full lifecycle, as well as institutional costs arising from developing climate adaptation strategies, increasing the awareness of adaptation risks at the local level, and investing in projects to improve capacity, monitoring, evaluation, and local learning, among others. This would effectively minimize, or even avert, these anticipated losses and damages.

If more transformative adaptation actions were taken, such as **switching soon-to-be unsuitable arabica coffee production areas to vanilla production (Scenario 3), local farmers would generate net economic gains of approximately $15.8 billion (compared with baseline Scenario 1)**, despite the higher upfront adaptation costs ($3.4 billion) as compared with Scenario 2 ($2.3 billion).[4] This is mostly due to the higher market value and productivity of vanilla as compared with robusta coffee. An investment of this magnitude would clearly avert losses and damages. However, it should be noted that efforts to breed high-quality robusta coffee and expand the specialty robusta market may narrow this gap.

BOX 3 | Economic Modeling of Climate Change-Induced Shifts in Ethiopian Coffee Production (Cont.)

Table B3.1 | Cost-Benefit Analysis of Coffee vs. Vanilla Production in Ethiopia

ESTIMATED COSTS AND BENEFITS OF THREE SCENARIOS (2015–2050), DR= 6%						
	Baseline Scenario (S1)		Incremental Adaptation Scenario (S2)		Transformative Adaptation Scenario (S3)	
	Under Maximum CC Impact (3°C increase)[a]	Under Minimum CC Impact (1.5°C increase)	Under Maximum CC Impact (3°C increase)	Under Minimum CC Impact (1.5°C increase)	Under Maximum CC Impact (3°C increase)	Under Minimum CC Impact (1.5°C increase)
Discounted total benefits (millions, US$)	19,275	21,715	21,733	24,156	40,735	43,155
Additional losses or gains of the adopted production system (millions, $)	-208 (losses from declined arabica production)	-256 (losses from declined arabica production)	2,441 (gain from robusta coffee production)		18,063 (gain from vanilla production)	
Discounted total costs (millions, $)	9,531 ($0 adaptation cost)		11,857 (of which $2.3 billion was for switching to robusta coffee)		15,142 (of which $3.4 billion was for switching to vanilla production)	
NPV (millions, $, 2015–2050)	9,744	12,184	9,876	12,299	25,593	28,013
Land area by 2050 (ha)	543,913	543,913	900,000	900,000	900,000	900,000

Notes: Abbreviations: dr: discount rate; CC: climate change; °C: degrees Celsius; NPV: net present value; ha: hectares; [a.] In Ethiopia, the mean temperature is projected to rise between 1.5 and 3°C by the 2050s (Adaptation Fund 2017).

Source: Analysis by WRI researchers.

Despite limitations in the nuances of the analysis, our findings provide insights into the economic implications of incremental versus transformative approaches in coffee production in Ethiopia and more broadly. In particular, **a comparison of the net economic gains across the three scenarios suggests that Scenario 3, the transformative adaptation scenario, may result in much greater society-wide economic gains.**

However, this analysis is not intended to imply that in all circumstances this approach should be employed where coffee production is impacted by climate change. Careful consideration should be given to local contexts including extent of climate impacts, community vulnerability, land use and resource use trade-offs, market variables, cultural and traditional dynamics, and social equity components. For example, this study did not analyze the impacts of a crop switch on women or the availability of water needed for vanilla versus coffee.

Moreover, the results of the analysis need to be approached with great caution, as the analysis was constrained by a lack of local data and strong assumptions were made based on more detailed field data reported in other countries, illustrating the need for further research of this nature.

Finally, one should also note that although Scenario 3 generates higher economic gains, this scenario is also associated with much greater adaptation costs, which implies higher financial risks for farmers. Hence, it is very unlikely that farmers will choose the transformative adaptation option without government assistance or external private sector investment.

Notes: [a.] Tefera and Tefera 2014; [b.] USGS and USAID 2012; [c.] Moat et al. 2017; [d.] Moat et al. 2017; [e.] Killeen and Harper 2010; [f.] Shriver 2015; [g.] Kifelew et al. 2016; [h.] Shriver 2015.

4.4 Reducing Risks of Crisis, Conflict, and Displacement

The losses and damages generated by climate change impacts can also be social in nature and escalate into social unrest, crisis, and conflict. In some situations, transformative approaches can help guide food systems to more sustainable futures, thus averting or minimizing losses and damages instead of allowing responses to occur haphazardly and devolve into crisis. This requires recognizing the need for widespread changes to what can be grown or raised where, to potentially ease current or future tensions, particularly around resource use. Such forward-looking action may increase the odds that alternative (in some cases, nonagricultural) livelihoods will be possible when needed if transformative pathways are started sooner rather than later. Brück and d'Errico (2019) summarize the linkages by noting that "resilience protects whatever development progress has been achieved so far and contributes to preventing conflict and humanitarian emergencies." For example, some farmers in Costa Rica are shifting from coffee production to citrus in response to increased heat and other climate change impacts, as well as volatile global coffee prices. These farmers can continue working in agriculture while reducing their risks and increasing household incomes (Carter and Tye 2018; Ferdinand et al. 2020).

The example in Box 4 highlights a transformation in livestock feed and related markets that has successfully avoided crisis and reduced the odds of conflict over watering points and grazing lands by mitigating the impacts of drought on herders in Ethiopia, thus averting socioeconomic losses and damages. In addition to the increased resilience that the example focuses on, this transformative approach to adaptation will also reduce overgrazing of already stressed rangeland, enabling forage plants—and the herders whose livestock depend on them—to bounce back more quickly once the rains come.

BOX 4 | FEED for Crisis Mitigation

Livestock production in Ethiopia is a major economic sector, contributing to the livelihoods of 60 to 70 percent of the country's population. Inadequate quantity and poor quality of and limited access to feed have impeded livestock sector development in Ethiopia and the ability of livestock owners to withstand the impacts of an increasingly variable climate.

In response, the U.S. Department of Agriculture (USDA) Food for Progress program designed the Feed Enhancement for Ethiopian Development (FEED) project to increase incomes of smallholder farmers by improving access to, and use of, consistent, affordable, high-quality feed that can support greater livestock and poultry productivity and efficiency. FEED project activities are broad-based, addressing feed resources on and off farms as well as farmers' ability to properly use them. A key component of this approach was the establishment of 24 commercial feed manufacturing enterprises built on the existing cooperative union system (cooperation organizations among farmers for sharing services and inputs, such as machinery, with legal trade representation). Because the unions are geographically dispersed, the enterprises are better able to use locally available grains and agro-industrial by-products; they can also maintain linkages with more distant sources that can be accessed when local supplies are inadequate to meet increases in demand, be that due to market expansion or drought. These enterprises enable the growth of livestock and poultry production in Ethiopia and constitute a new piece of the food production system in the communities they serve—one that provides added flexibility in responding to shocks to the system; that is, greater resilience and food security.

The outcomes of the 2015–16 drought illustrate these benefits. The drought was, by many accounts, the worst in 50 years. Some of the worst impacts were in the northern region of Tigray. According to information provided by the project partner, ACDI/VOCA, 661,008 animals in Tigray were at risk, with 163,210 identified as needing immediate assistance. Government agencies and nongovernmental organizations in the region turned to FEED project unions for assistance in mitigating the effects of the drought. Because of the USDA's original investment through the FEED project, as well as the commercial nature of the business that sustains it, infrastructure was already in place, as were ingredient procurement and distribution systems to respond to the drought. The unions were able to distribute concentrated feed to more than 307,000 animals owned by almost 119,000 farmers. According to local interviews, not a single animal receiving supplemental feed was lost. In outside areas that were not part of the FEED program, livestock productivity decreased, but there were no animal deaths, migrations, or forced livestock sales. This greatly contrasts with previous drought years where, nationally, millions of animals died. Projects like this one will become all the more critical as the frequency and severity of droughts increase.

Source: Adapted from Salman et al. (2019).

CHAPTER 5

CALLS TO ACTION TO ACCELERATE TRANSFORMATIVE ADAPTATION

As noted in the *Adapt Now* report by the Global Commission on Adaptation, adaptation actions can be grouped into three critical areas, all of which are essential for advancing adaptation action: understanding, planning, and financing (Bapna et al. 2019).

The following three subsections loosely follow the same structure to summarize the authors' perspectives on how the most important points from the preceding evidence can be converted to action on transformative adaptation. The subsections issue calls to action describing what research organizations, governments, and funding entities can do to advance understanding of and planning and financing for transformative approaches to agricultural adaptation. If this group of actors can mobilize to support the right research, actionable plans, and funded projects, we will be much closer to achieving the adaptation goals set forth in the Paris Agreement and the United Nations Sustainable Development Goals (SDGs). At the same time, we will be advancing the Global Commission on Adaptation's recommendations and thereby ensuring long-term, sustainable, equitable resilience for smallholder farmers and herders.

Note that many of the citations included in this section refer to the TACR topical papers on crop research and development (Niles et al. 2020), climate services (Ashley et al. 2020), and livestock production (Salman et al. 2018), as well as additional WRI publications on transformative adaptation (Ferdinand et al. 2020; Tye and Grinspan 2020). Specific references to how these calls to action can support and enhance the Global Commission on Adaptation's Agriculture and Food Security Action Track goals are included.

5.1 Understanding

Expand research and development to make climate risks visible and engage farmers and herders in identifying transformative solutions for building long-term resilience

International, national, and subnational agricultural research systems and related mechanisms—for example, extension services, which work directly with farmers to distill the results of research to on-the-ground actions in their fields, and producers' associations, which can also promote new practices and market opportunities—all have a role to play in advancing understanding of long-term, systemic change. In particular, they can help fill the many gaps in data, analysis, and conceptual understanding in this new area of research. These research systems and mechanisms are well-positioned to identify where and when significant shifts will be needed and what potential climate adaptation solutions exist and engage those most vulnerable. They have improved dramatically over recent decades in their capacity to meet farmers' research and information needs thanks to technological advancement, interorganizational collaboration, and participatory engagement with communities.

As explored in *Opportunities for Crop Research, Development and Adoption to Drive Transformative Adaptation in Agriculture* (Niles et al. 2020), investments in crop research and development (R&D) have yielded important technological advancements—such as faster breeding times for more stress-resistant, productive, and nutritious crops—to support incremental adaptation. However, the paper concluded that more needs to be done that goes beyond the limits of improved breeding to increase farmers' access to new and more diverse crops, create more robust and agile seed production and distribution systems, and establish creative market and financial mechanisms for the faster adoption of new crops suitable for future climates.

Similarly, *Transformative Adaptation in Livestock Production Systems* (Salman et al. 2019) found that systemic shifts to improve the long-term resilience of livestock production may include relocating livestock production systems, introducing new livestock species, or transitioning into or out of livestock for other agricultural or nonagricultural livelihoods. Salman et al. (2019) identified specific areas in need of additional research and investment, without which some livestock systems may not withstand intensifying direct and indirect climate impacts such as changing disease dynamics and could exclude or disadvantage those living in poverty and other vulnerable groups.

In addition, *Applying Climate Services to Transformative Adaptation in Agriculture* (Ashley et al. 2020) concluded that while climate services (CS) have generated sophisticated knowledge about climate change and its impacts on agricultural production across timescales, CS could be enhanced to support transformative adaptation. Additional findings from this paper are expanded upon in Section 5.1.3.

This section draws upon these findings to identify key research areas that are needed to speed the scaling of longer-term, systemic adaptation. This process has thus far been slow, perhaps due to reasons that include more immediate priorities and the increasing uncertainty of climate projections further into the future; a lack of capacity to envision and understand the full ramifications of future climate impacts; an inability to access critical information and technologies; inadequate research infrastructure and networks; and too few private-public partnerships and suitable legal frameworks (e.g., intellectual property law for newly developed crop species) needed to expedite adaptation solutions.

5.1.1 Focus on the needs of the most vulnerable users

Research efforts must focus squarely on the needs, experiences, and solutions of those living in poverty and those most vulnerable to climate change impacts—especially smallholder farmers, fishers, and herders.

Smallholder farmers, fishers, and herders, as well as Indigenous peoples and those living in poverty, are often among the most vulnerable, but they also have a wealth of experience to contribute to the evidence base regarding which adaptation measures work best in particular contexts. Greater collaboration with these groups is needed for effective on-the-ground implementation of adaptation action (Ferdinand et al. 2020; Tye and Grinspan 2020). For example, participatory methods to improve seed systems can be helpful. In Ethiopia, locally organized and managed trial plots of new varieties and further breeding to adapt them to local conditions has improved community seed systems, leading to immediate benefits and providing a channel for the dissemination of new crops as they are developed (Niles et al. 2020).

Investments are also needed to improve the resilience and productivity of traditional and wild crops that may not appear in global supply chains but are essential to local food security and nutrition. While generally lower yielding than hybrid varieties, they may be more resilient to drought and other expected climate changes, are often nutritionally dense (Kole et al. 2015; Tadele and Assefa 2012), and are important for regional food production and food security (Naylor et al. 2004). The application of modern technologies could improve their productivity without losing their nutritional value and durability (Niles et al. 2020). Enabling greater reliance on locally appropriate traditional crops by applying modern crop breeding techniques to increase their productivity while retaining climate-resilient traits would be transformative.

Investments in crop R&D must be matched by assistance in helping farmers adopt new crops. This entails improving access to and participation in improved seed systems and agricultural input markets so that farmers can effectively grow and sell new climate-resilient crop varieties and species while better meeting their food security needs. Additional research is needed into how to make extension and adoption pipelines more effective at ensuring that new technologies and crops are both appropriate for and accepted by farmers, especially those that are at high risk and have limited access to financial resources, land, and information.

People living in poverty and other vulnerable groups must be able to make decisions regarding systemic shifts at all links in value chains, so that no one is left behind. Key inputs, such as new varieties of crops, fish, and livestock—as well as information required to successfully produce, harvest, process, and market them—must be made more accessible to marginalized farmers, fishers, and herders.

5.1.2 Emphasize research needed for transformative adaptation

The research agendas of global research systems, such as the Consultative Group on International Agricultural Research and the UN Food and Agriculture Organization; National Agricultural Research Systems; and local agricultural research and outreach organizations should build capacity to promote and engage in transformative adaptation approaches to food system shifts.

More research is needed on how crops and livestock will respond to long-term changes in temperature, shortened rainfall seasons, shifts in precipitation and wind patterns, and impacts on pollinators, among others. These data could inform understanding of which crop and livestock varieties may be approaching thresholds that could make continued investments in maintaining current systems less beneficial than investing in alternatives (including indigenous varieties). While some slow-onset events, such as increasing coastal freshwater salinity, have obvious effects on agriculture and aquaculture, understanding is more limited of how more subtle changes in climate, such as more wind and fire or higher humidity, can threaten the viability of food systems.

Global research networks like CGIAR and the FAO play a critical role in this type of research, and in promoting global food security through research and innovation, including by helping farmers better manage climate change risks. The CGIAR's newly launched Research and Innovation Strategy highlights systems transformation to frame the research, and places agriculture within the broader context of how water and land systems will be affected by and must be adapted to the climate crisis, as explained in Box 5, which references the *Adapt Now* report (Bapna et al 2019).

While generally not as well funded or sophisticated, National Agricultural Research Systems (NARS) play a critical role in the early stages of building the capacity to promote and engage in food system shifts for climate resilience, particularly in sub-Saharan Africa and Southeast Asia. The ability of NARS to conduct crop R&D is a prerequisite for transformative adaptation, which governments and adaptation funders should prioritize making investments in—specifically, in efforts to decrease breeding times; expand gene banks and related data systems, the range of crops researched (e.g., traditional and orphan crops), and the diversity of available genetic breeding material; and scale up participatory breeding approaches.

In addition, local research organizations (often local universities and colleges) and nongovernmental organizations (NGOs) such as those that work closely with farmers also need greater capacity to encourage farmers to experiment with new types of crops and livestock and other transformative elements. A greater share of funding must be channeled to them to help identify what will work in particular contexts.

Five specific actions could help both global and national agricultural research organizations improve crop breeding to better support long-term, systemic change:

1. Develop a suite of technological strategies. There is no single best strategy for breeding climate-resilient crops, and different breeding strategies may confer a range of agronomic,

BOX 5 | ADAPT NOW: Expanding the Research Agenda of CGIAR

The Consultative Group on International Agricultural Research (CGIAR) system is embarking upon a transition to fully embed climate change in every aspect of its new 10-year strategy. The Global Commission on Adaptation's Agriculture and Food Security Action Track includes the aim of doubling the scale of investment in agricultural research through the CGIAR system to support 200 million small-scale producers in adapting their farming systems, livelihoods, and landscapes to be more climate resilient by 2030.

While doubling investment and integrating climate change into all research work streams is important, how that investment is allocated is even more critical. The CGIAR research agenda can be made more transformative by explicitly identifying which types of crops and livestock will be most resilient in significantly altered conditions.

Particular attention must be given to vulnerable smallholder farmers and herders, who must be better engaged in setting the CGIAR's regional research agendas and participating in their implementation to ensure that their needs are addressed.

The CGIAR system could specifically promote transformative actions such as considering entirely different types of crops and livestock where needed, accelerating implementation of significantly new technologies, and recognizing that in some cases entire landscapes will need to shift from one type of production to another.

economic, environmental, and social benefits and challenges. Specifically, greater investment is needed to support precision phenotyping, trials under a range of environmental conditions, and the incorporation of traditional, wild, and climate-resilient crops and traits into breeding cycles. By developing more diverse sets of crops with wider ranges of genetic traits, crop researchers will be better able to develop the crops needed under transformative adaptation scenarios.

2. **Speed up the crop and livestock breeding process from development to adoption.** Current average breeding times in low-income countries are seven to nine years from development to adoption, which hinders the ability to get new types of crops and livestock into the hands of farmers as quickly as will be needed for transformative adaptation to become more widespread. To keep pace with a changing climate, this should be brought down to three or four years, as is happening in developed countries, by accelerating trials, building out crop profiles, and reforming intellectual property laws (Niles et al. 2020). Improving seed distribution and protective mechanisms for crop and livestock genetic diversity requires additional investment, as does generating better information regarding genetics and seed adoption.

3. **Improve pest and disease surveillance networks.** Very little is known about shifting pest and disease dynamics in changing climates. Expanding surveillance networks and building out data platforms for agricultural pests and diseases would enable existing food systems to be maintained and increase the odds that emerging ones will be viable.

4. **Promote intersectoral, interregional coordination.** Determining sustainable solutions to long-term adaptation challenges will not be possible without looking at regional- and country-level analyses of how other sectors will impact agriculture in the future, especially those related to water use, industrial development, and land use planning. Agriculture will need to shift according to not only climate change impacts but other sociopolitical dynamics—making location-specific intersectoral and interregional coordination platforms essential.

5. **Develop capacity to undertake a range of analyses.** In addition to traditional cost-benefit analyses that focus primarily on crop yields, greater emphasis should be placed on accounting for externalities (i.e., hidden costs, often to environmental sustainability), trade-offs, and co-benefits. In addition, social impact analyses should be more widely used to better understand which types of crops, livestock, technologies, and other interventions will be a good fit with local cultures and preferences. Political economy analyses can identify barriers to interventions reaching and being adopted by those living in poverty and other vulnerable groups. Foresight analysis, which has been defined as "a systematic, participatory, future-intelligence-gathering and medium-to-long-term vision-building process aimed at enabling present-day decisions and mobilizing joint action," has also been used as a tool for transformative scenario planning (UNDP 2014, 7).

5.1.3 Enhance climate services and information platforms to support transformative adaptation

Research organizations, with support from governments and funding entities, should enhance climate services and information platforms to enable identification of hotspots and aid decision-makers in designing transformative pathways.

As Box 6 summarizes, climate services (CS) could be enhanced to better support transformative adaptation by identifying *transformation hotspots*, assessing more resilient options, and mapping transformative pathways. Several studies and initiatives have aimed to identify climate change hotspots in terms of where communities will be the most vulnerable, most exposed, and most sensitive to climate impacts (Mani et al. 2018; UCS 2011; Parker et al. 2019; FAO 2014). However, few research initiatives have stress-tested the limits of how much specific regional food systems can adapt to the severity of climate change impacts expected under different emissions scenarios or in response to combinations of climate change impacts, nor the adequacy of current adaptation interventions for preventing steep productivity declines and crises in transformation hotspots.

Tools for analyzing probabilistic scenarios of various climate impact scenarios occurring over the longer term could include greater consideration of slow-onset events and decadal and longer-term (2050 and end-of-century) climate change projections (Ashley et al 2020).

By the same token, greater investment in developing tools to help identify opportunities to produce crops that may be new to a region will be critical to incentivizing farmers to recognize that substantial changes are needed. Most currently available crop suitability models focus on identifying which globally traded staple crops will no longer be suitable in particular areas due to climate change impacts. Future models need to identify a broader range of crops, some of which may be non-market traditional varieties, that will become *more* suitable (Kole et al. 2015; Tadele and Assefa 2012).

While some studies have assessed crop suitability under various climate change scenarios, along with more general climate change impacts on agricultural livelihoods (see Box 3 for an example), few researcher programs have been systematically designed or implemented to provide holistic information and analyses for entire regions or suites of crops or livestock species to determine tipping points. FAO's Modelling System for Agricultural Impacts of Climate Change (MOSAICC) is an example of an existing model that integrates components related to climate, agronomics, hydrology, economics, and forestry (FAO 2015). However, application of the model seems to be limited to a handful of countries (e.g., Uruguay, Paraguay, Indonesia, Morocco, Peru, Philippines, Malawi, Zambia), and its climate components are based on historical climate variability that does not adequately reflect climate change predictions. IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) (Robinson et al. 2015) is another promising example. It was developed in the early 1990s to consider the long-term challenges facing policymakers in reducing hunger and poverty. It has been expanded and improved repeatedly to respond to increasingly complex policy questions and the state-of-the-art of modeling, and now includes a network of linked economic and market, water, and crop models, as well as the capacity to analyze climate change impacts. Models like these could be made accessible to non-experts and prioritized for rapid scaling to improve adaptation efforts.

More localized and specific analysis of crop viability and options for new crops should include input from farmers and herders regarding their observations, experiences, and preferences. Research is also needed to assess the costs and benefits of potential new crops, the socioeconomic impacts on different communities and groups, and the markets and policies needed for new crops to translate into viable livelihoods and sustainable climate-resilient economic development (Niles et al. 2020). These insights will reduce the risk of spending limited resources on maladaptive, unsustainable, or unwanted projects or programs.

Generating this information will require more investment in robust baseline data collection and high-resolution, contextualized data (Ashley et al. 2020). The satellite data and related models that most existing hotspot-type analyses are based on are generally not designed to predict system

BOX 6 | Enhanced Climate Services for Transformative Adaptation

- New types of information to identify transformation hotspots and determine best-fit solutions (e.g., crop/livestock climate suitability thresholds, scenarios of increased frequency of extreme events, market projections)
- Expanded time horizons (e.g., longer-term scenarios beyond 10 years; short-, medium-, and long-term adaptation options)
- Tailored, bundled information: Different transformative pathway actors require different "bundles," or combinations, of information, which should be tailored to meet their needs

Source: Derived from Ashley et al. (2020).

tipping points. This is particularly true for water data, as watershed dynamics are highly complex and difficult to model, and meteorological stations are spotty in many countries. Model predictions for precipitation in particular are often based on broad assumptions, and often reveal too broad a range of possibilities to be useful for medium- and long-term agricultural planning. More open access to climate and environmental data collected by governments or private companies is also needed. Farmers can also play an important role in improving available information through systems that enable them to share their observations with other farmers and researchers, as described in Box 7 (Ferdinand et al. forthcoming).

To better support policymakers in applying transformative adaptation to planning processes, specific types of information for better determining crop suitability should be tailored to their needs and bundled together. For example, government policymakers would require long-term scenarios that include more transparent land tenure and socioeconomic data, while private sector investors might want to know more about market niches, risk mitigation approaches, and opportunities for novel crops. Adaptation funding entities could require

BOX 7 | ADAPT NOW: Assisting Autonomous Adaptation through Digital Advisory Services

As part of the Agriculture and Food Security Action Track, the Global Commission on Adaptation has developed a partnership with the German Federal Ministry for Economic Cooperation and Development, the World Food Programme, and other partners to expand two-way data sharing and access to weather and seasonal forecasts, pest and disease early warnings, digital soil maps, and information on adaptive production practices.

Transformative adaptation could be incorporated in the development of innovative and adaptive digital advisory services by including information on long-term future climates, suggestions for alternative crops for specific hotspots, information on how to cultivate them and their required inputs, and a platform for sharing lessons learned by innovative and entrepreneurial farmers.

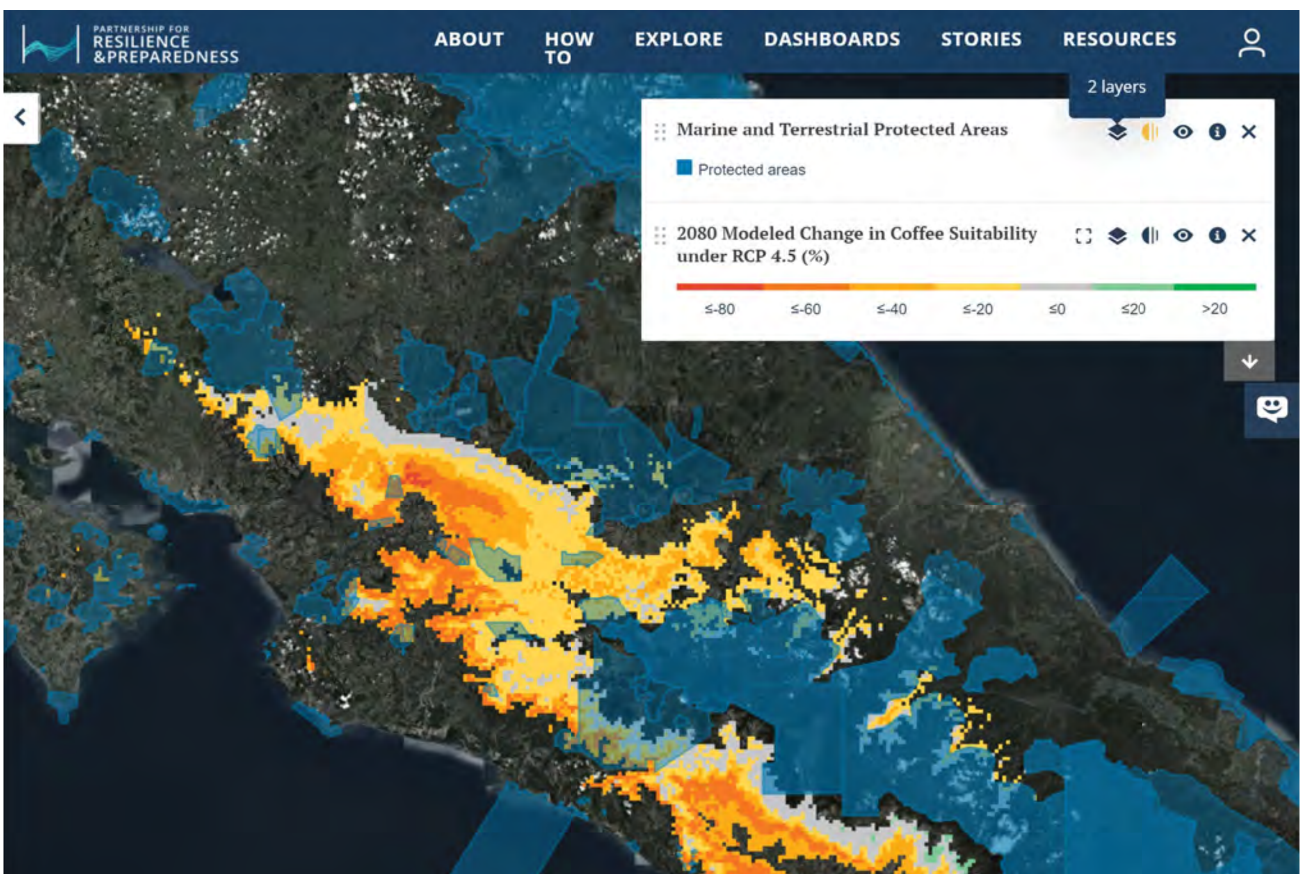
Source: Adapted from Ferdinand et al. (forthcoming).

information including social safeguards and the effectiveness of various interventions in similar systems. Strengthening laws regarding the security of land tenure, particularly for women, may be necessary to encourage farmers to invest more in long-term adaptation strategies.

Analyses that look at intersectoral trade-offs on natural resource use, socioeconomic variables, international/domestic price and market models, sociocultural variables, and ecological/environmental impact assessments, among others, will be more useful to policymakers with broad scopes of responsibility, and will also facilitate mainstreaming climate change adaptation across multiple sectors. This is particularly true if the outputs from these often-complex analyses are presented in a format that is accessible to policymakers and customized for them. For example, agricultural labs in Madhya Pradesh have developed and applied a Water Evaluation and Planning system–based decision support tool that can simulate agricultural water demand in river watersheds based on IPCC future climate projections (Aggarwal et al. 2018), although it is reported by some that this tool is quite complex to use.

Producing and packaging tailored information that includes many of the factors that concern decision-makers also requires finding clear and compelling ways of visualizing complex data (Tye and Grinspan 2020). Figure 9 features an example of the use of a straightforward data visualization tool, PREPdata, which may be more accessible to decision-makers than more complex platforms.

Figure 9 | PREPdata Visualization of Changes in Coffee Suitability in Costa Rica



Source: Costa Rica coffee data: Ovalle Rivera 2018. Visualized using PREPdata platform, prepdata.org.

5.2 Planning

Transformative approaches to adaptation must be integrated into planning processes.

For transformative approaches to adaptation to actually build long-term, sustainable resilience, they must be integrated into national and subnational planning and budgeting processes and then implemented. Long-term, systemic change can best be mainstreamed and scaled up by embedding transformative pathways in the full range of adaptation policies and planning mechanisms, from the international to the local level. This will require improved coordination between local and national governments, as well as among governments, funding entities, and research organizations, all while using transformative approaches to plan over longer time scales.

For transformation to occur at a broader scale more quickly, governance structures at all levels, from national to local, must remain robust for the decades that will be required to implement coordinated sequences of actions over many years, despite changing power dynamics that can include differing leadership, regional or international issues, or groups within countries. Other useful measures include improving institutional structures and networks; eliminating inequitable policies; and improving access to information, data, and credit. In addition, building leadership skills, capacity, and institutional memory among technical leaders who are unlikely to change with each new administration—particularly those in Ministries of Finance and Planning—may also be helpful. Budgets must integrate climate adaptation considerations and prioritize transformative adaptation where and when it is needed. Finally, the UNFCCC and its organizations have a role to play in building momentum among Parties to the Paris Agreement for this approach to be more widely applied.

It is important to note that addressing the need for long-term, systemic change may be politically risky and unpalatable when attention is focused on the next election rather than decades in the future—but reducing future conflicts and chaos, creating sustainable jobs and new enterprise opportunities, and fueling economic growth make this a worthwhile endeavor. This case can more effectively be made if policymakers are armed with the right information.

5.2.1 Mainstream transformation into national and subnational planning processes

National and subnational governments should integrate into planning processes an understanding of when, where, and how food systems will need to shift over the coming decades.

Effective design of transformative pathways depends upon integrating the types of research and analysis described in Section 5.1 into plans and policies. These can include National Adaptation Planning processes, of which 21 have been posted on the UNFCCC website as of mid-February 2021, while over 90 are currently in the works. Countries can also include transformative pathways in broader multisectoral development plans and policies and align them with plans to achieve the SDGs (Carter et al. 2018). Tools like the NAP-SDG iFrame can assist countries in aligning development agendas (UNFCCC 2018a).

Plans and policies must recognize that many systems—such as water, trade, and employment—operate across boundaries, both geographical and political, and that shifting food systems will often rely on better collaboration around management of cross-boundary systems. Transformations also require linking systems that operate at many scales; for example, agricultural R&D networks should be connected from community to national and international levels, while food systems operate at local, regional, national, and global scales.

5.2.2 Include all stakeholders, especially those often marginalized, in decision-making

Planning for transformative adaptation should center on inclusive, participatory processes that engage a diverse range of stakeholders, including smallholder farmers, herders, and fishers from groups that may often be marginalized in decision-

making, such as women, youth, and Indigenous peoples, so that no one is left behind.

The types of fundamental, systemic changes described in this report will almost always be challenging to implement, in part because what farmers and herders produce is often central to their identity, sense of place, and pride. Even so, engaging communities in making difficult decisions about their futures is preferable to turning a blind eye to foreseeable crises. This will require governance structures such as participatory planning processes that facilitate effective two-way communication from the local to the national levels, as well as sufficient financial and technical support for communities to enact food system shifts. Farmer-producer cooperatives and similar organizations, as well as relevant local and regional NGOs, can play an important role, particularly in introducing new interventions to their areas and in identifying pioneer farmers.

Farmers, fishers, and herders and their communities need to be involved from the onset in deciding when, where, and how system shifts will occur (within the scope of what scientific data indicate will be feasible). In some situations where agriculture is already becoming marginal and severe climate change impacts are anticipated, farmers, fishers, and herders may have to move away from culturally significant species to more climate-resilient ones or, more drastically, out of farming altogether.

Governments should base planning on transparent information and consultations with a range of stakeholders to make evidence-based decisions regarding the types of transformative adaptation that would be good investments and offer social and economic co-benefits once future climate impacts are considered (Salman et al. 2019; Ashley et al. 2020; Niles et al. 2020).

Even broad-scale interventions will still need to be responsive to the local context because measures appropriate in one part of a region may not work well in other areas (due to differences in soil, topography, microclimates, and other factors). For example, adaptation experts interviewed in the Hindu Kush Himalaya region said that scaling up the shift to a new, climate-resilient crop (e.g., apples; see Box 1) might not be a sustainable solution for many communities due to diverse cultural and environmental conditions in this mountainous region.

Interviewees in the Hindu Kush[5] and Ethiopia[6] suggested that the proper scale for implementing systemic change might be at the watershed (or even

micro-watershed) level. Communities within the same watershed will have interconnected water, soil, and microclimate dynamics, and what happens upstream will affect those downstream, and vice versa, which could bring diverse stakeholders together around common adaptation goals and methods.

As previously mentioned, where transformative adaptation is already occurring, it is often autonomous and unplanned, and is being led by pioneer farmers who tend to have better access to land, credit, information, and other resources that enable them to take the risks and invest in new alternatives. Cases of autonomous adaptation have been more prevalent so far than strategically planned interventions, but raise concerns that those who do not have sufficient access to these resources will not be able to engage in transformation where and when it is the best response. This can lead to greater consolidation of wealth and power, leaving those living in poverty and other vulnerable groups further behind.

Governments can partner with research organizations to identify autonomous transformative adaptation and related shifts that are already occurring. They could then scale up existing strategies through policies and financial instruments that make the necessary resources available, including to farmers and herders who are living in poverty and otherwise marginalized. Research organizations can help identify key enabling conditions and barriers that poorer farmers face and suggest policy solutions such as improved access to information and credit.

5.2.3 Link transformative adaptation to the UNFCCC process

The UNFCCC can facilitate and catalyze the development, dissemination, and use of knowledge to advance transformative adaptation policies and practices. The imperative toward long-term, systemic shifts should be part of ongoing discussions of the Warsaw International Mechanism for Loss & Damage associated with Climate Change Impacts (WIM), the Nairobi Work Programme (NWP), and the Koronivia Joint Work on Agriculture (KJWA), as well as the preparation of NDCs, NAPs, and other reporting requirements. There is little guidance and there are few examples available to Parties on how to incorporate this approach to adaptation into plans, policies, and funding proposals. UNFCCC bodies can play an important role in creating and disseminating this information. Given the number and diversity of stakeholders expected to be engaged through the UNFCCC, these multilateral bodies can play an important role in driving action, setting the pace of change, and providing guidance.

Loss and damage, which refers to impacts of climate change that have not been or cannot be avoided through mitigation and adaptation efforts (Van der Geest and Warner 2015), is addressed by the UNFCCC through the WIM. Avoiding or reducing loss and damage could be a main driver for transformative adaptation in agriculture. Such approaches are mentioned as a key area of work on comprehensive risk management through the Loss and Damage Work Programme of the WIM. Although a few relevant examples have been widely documented, such as Farmer Managed Natural Regeneration in the Sahel, substantially more attention should be given to this aspect of the work program, with a specific emphasis on agriculture and food security. The next update to the WIM Executive Committee's work plan, which was scheduled to be reviewed in 2020, offers an entry point for sharing examples and lessons learned, including those produced by the TACR project. The Executive Committee could also consider how the knowledge and expertise it has developed since its creation could be shared with and support the development of the KJWA, through activities such as joint workshops, research, or policy analysis.

The Nairobi Work Programme could incorporate a specific thematic focus area on transformative adaptation. Its Lima Adaptation Knowledge Initiative in particular offers an opportunity to foster regionally specific dialogue among Parties, observers, and other organizations on how best to enable transformation where and when it is needed. Sector-specific development, dissemination, and use of relevant knowledge, including for agriculture and food security, could be advanced by this cross-cutting initiative. The NWP could also promote greater investment in and use of tailored analyses, which could highlight impacts such as drought, water scarcity, and land degradation, or those on specific ecosystems such as oceans, coastal areas, mega deltas, coral reefs, and mangroves.

The UNFCCC's Least Developed Countries Expert Group (LEG) could continue to lead development of improved NAPs for least developed countries that incorporate transformative approaches to adaptation. Sessions on this topic during the 2018 and 2019 NAP Expos enabled Parties and supporting organizations to share experiences and ideas. LEG could rally countries to request improved guidance on long-term, systemic approaches to agricultural adaptation, of which little currently exists.

The Koronivia Joint Work on Agriculture could promote the development and implementation of transformative pathways. Initiated in 2017, KJWA asks Parties and observers to submit their views on a range of methods and approaches to address climate change impacts on agriculture (UNFCCC 2018b). The challenges of and promising approaches to making long-term, systemic change should be explicitly considered in the planned KWJA workshops on livestock management and the socioeconomic and food security dimensions of climate change in the agriculture sector, which took place virtually during the Climate Dialogues in November and December 2020 due to the COVID-19 pandemic. Parties could integrate long-term, systemic adaptation into potential future topics for the KJWA to include at COP26—for example, improving crop R&D with a focus on seed systems to enable agricultural transformations; building capacity for long-term planning; analytical approaches to identify where and when transformative change will be needed; options for alternatives; and policy and market incentives.

Adaptation communications to the UNFCCC, including nationally determined contributions, national communications, and national adaptation plans—which many countries are currently updating or drafting in the run-up to COP26—offer an additional way for Parties to signal their recognition of the need for long-term, systemic resilience that engages policymakers across ministries and disciplines.

Although more than 90 percent of current NDCs mention agriculture in some way (such as inclusion in an economy-wide target or specific policies and actions that address agriculture mitigation and/or adaptation), the current round of NDC updates presents an opportunity to be more explicit about what each country intends to achieve, how to get there, and what support is needed (Ross et al. 2019). These enhanced NDCs should also reflect the perspectives outlined in the UNFCCC's Local Communities and Indigenous Peoples Platform to ensure that these often marginalized groups are at the core of efforts to reduce or minimize countries' vulnerability to climate change. The enhanced NDCs should also be gender-responsive as per the UNFCCC's Gender Action Plan. As for NAPs, a key objective of the NAP process is to develop and enhance Parties' long-term capacity for planning and implementing adaptation actions. As of November 2020, 125 out of 154 developing countries had undertaken preparation and/or implementation of these processes (UNFCCC 2020); as of mid-February 2021, 21 of these countries had completed and posted their first NAPs as per the NAP Central website.

5.3 Finance

Finance to mobilize resources is needed to accelerate transformative adaptation.

Entities that fund action on climate change, both multilateral and bilateral, are recognizing the need to increase the amount of funding devoted to adaptation. However, given the challenges that the global food system faces, a massive increase in funding for agricultural adaptation is urgently needed, for both incremental and transformative approaches.

Adaptation finance increased 35 percent from 2015/2016 to 2017/2018—from $22 billion to $30 billion (Buchner et al. 2019). Global adaptation funding for the agriculture, forestry, land use, and natural resource management sector increased from $5 to $7 billion from 2015/2016 to 2017/2018. It continued to be the second-highest-funded sector after water and wastewater management (Buchner et al. 2019). Box 8 offers a reference for further detail.

BOX 8 | Multilateral Climate Funders of Adaptation

Binet et al. (2021) conducted a recent evaluation of the Green Climate Fund's adaptation portfolio and approach and found that there are six multilateral climate funds particularly relevant to adaptation: the Least Developed Countries Fund, the Special Climate Change Fund, the Adaptation Fund, the Pilot Program for Climate Resilience, the Adaptation for Smallholder Agriculture Programme, and the Green Climate Fund. More information about how these funds are structured and comparisons among them can be found in the report.

Agriculture is the highest-funded sector in the adaptation portfolios of the Adaptation Fund, the Least Developed Countries Fund, the Pilot Program for Climate Resilience, and the Green Climate Fund. Approximately 45 percent of adaptation projects from these funds have an agriculture focus (WRI 2018).

However, adaptation funding overall amounts to only 5 percent of tracked climate finance data (Buchner et al. 2019). At this rate, adaptation funding will continue to fall short of the $280–500 billion projected to be needed annually by 2050 (UNEP 2018). Given the magnitude of the agricultural adaptation challenge, the amount allocated to this sector is unlikely to be enough. The amount of funding must rapidly be scaled up to be at least in line with the Paris Agreement commitments of mobilizing $100 billion per year from 2020 onward. While the costs of transformative adaptation have not yet been calculated, they are likely to be high, given the extensive scale and scope of the changes it will entail—although avoiding losses and damages is likely to pay off over the long term. This section explores how expanding adaptation action to include transformative adaptation and the additional investments it will require might be accomplished.

5.3.1 Improve alignment among funders

Adaptation funders, including bilateral and multilateral agencies, need to develop complementary approaches to transformation and shift their funding modalities to support projects and programs that identify and prioritize building resilience in transformation hotspots.

As described previously, adaptation funders have divergent perspectives on what transformative adaptation entails—which makes coming together around common goals and best practices difficult. In response, the TACR project offered a definition for transformative approaches to agricultural adaptation that, if widely adopted, could remove some of the ambiguity that may be limiting progress.

Regardless of whether or not this happens, closer collaboration could help ensure that this diversity of viewpoints can be brought together to create a complementary range of mechanisms to better manage long-term, systemic risks through transformative adaptation. Adaptation funding entities, both multilateral institutions, such as the Green Climate Fund, Adaptation Fund, and World Bank, and bilateral donors, such as the U.S. Agency for International Development, the German Federal Ministry for Economic Cooperation and Development, and the British Foreign, Commonwealth & Development Office, could also more deeply engage with peer organizations, leverage each entity's comparative advantages, and broaden their focus from isolated projects to wider initiatives. Funders could concentrate specifically on leveraging their respective comparative strengths to better determine whether, when, and where transformative approaches may be needed and encourage proposals that reflect this. They could implement such changes by using common (or at least complementary) funding objectives or criteria (such as the three points in the TACR definition outlined in Section 1.1).

New mechanisms could be put in place to improve coordination—perhaps along the lines of what the NDC Partnership does among countries working to implement their NDCs and funders who are supporting them. The Green Climate Fund, Global Environment Facility, and Adaptation Fund have undertaken efforts to strengthen their coherence and coordination around other issues and could take on systemic adaptation as well. Other funding entities could follow suit.

Adaptation funders could also encourage or even require proposals for agricultural adaptation and related sectors (e.g., water resources) to incorporate more information on long-term climate impacts and identify how the proposal's actions contribute to transformative pathways. Where climate change is expected to make existing food systems nonviable, proposals should consider designing pathways for a range of climate scenarios that acknowledge trade-offs among sectors and stakeholders for each of them. Box 9 summarizes the *Adapt Now* report's recommendation on this topic.

5.3.2 Incentivize transformation

Governments and the private sector can create adaptive incentives and disincentives to initiate and sustain shifts in food systems.

Governments and the private sector, including banks and financiers, could create market incentives and disincentives such as taxes, fixed pricing, and other market mechanisms to provide opportunities (or remove barriers) for farmers to invest in unfamiliar and potentially risky transitions to other types of agricultural (or nonagricultural) livelihoods (Niles et al. 2020). Grants, loans, subsidies, taxes, and improved co-financing tools, among others, could also provide farmers with opportunities to invest in such transformations (Bapna et al. 2019). Insurance may also have a role to play over the short term, although its long-term ability to continue paying out when disasters become more frequent and severe is questionable. Redesigning subsidy structures for new crops and their inputs, promoting marketing campaigns, and encouraging selective seed market development are additional options to encourage adaptive crop switches (Niles et al. 2020).

BOX 9 | ADAPT NOW: Diversification and Transformation

The *Adapt Now* report[a] recommends that the adaptation community help small-scale farmers better manage increased variability and climate shocks by supporting on- and off-farm livelihood diversification and increased market access.

This recommendation is closely linked to the impending need for large-scale, systemic shifts to better manage climate impacts. Both diversification and transformative adaptation can be promoted through particular types of actions such as switching to different types of crops and livestock where needed, changing to significantly new technologies, and/or recognizing that in some cases, entire landscapes will need to shift from one type of production to another.

Farmers and other rural people will need financial and technical support to make transformative approaches to adaptation more accessible, diversify their incomes as they transition to alternative farming systems, or even leave farming altogether in situations where no type of agriculture is viable.

Note: [a] Bapna et al. 2019.

Market incentives and disincentives are likely to be a particularly powerful tool to encourage the investments in climate-resilient crops and livestock that will be required in transformative adaptation scenarios. For example, investment in crop R&D, as well as what farmers decide to grow and what consumers choose to buy, is often dictated by the market and a reflection of consumer (and corporate) preferences. Based on current and future research that indicates which crops may be suitable where (considering climate impacts), policymakers could create market incentives for climate-resilient crops, including traditional crops. Decentralized agro-processing of new crops near where they are produced could also incentivize production of new agricultural products while providing additional jobs and income, and ease entry into new markets.

Table 1 includes three examples from India of water-related financial incentives and disincentives with the potential to lead to transformative change.

Policy decisions regarding incentives, such as where to institute agricultural subsidies, should reflect the complex webs of context-specific factors and be tailored to specific regions and ecosystems, rather than applied uniformly across countries and regions. For example, subsidies to encourage greater production of thirsty crops should be limited to humid watersheds and tailored to promote more suitable crops in areas with less water availability, even in cases where this seems contrary to generating the greatest short-term profits. Building resilience over the longer term provides greater stability and benefits to a wider

Table 1 | Financial Incentives and Disincentives for Agricultural Water Use in India

METHOD	PURPOSE	EXAMPLE
Reduction in electricity subsidies	Manage groundwater and electricity demand	To manage groundwater demand, a centrally sponsored energy policy reform, referred to as Pandit Deen Dayal Upadhyaya Gram Jyoti Yojana, which focuses on rationing farm power supply through interventions in electricity infrastructure, was introduced in the state of Gujarat. It was then expanded to other states such as Rajasthan, Andhra Pradesh, Haryana, Punjab, Karnataka, Maharashtra, and Madhya Pradesh. This scheme has not only led to a more efficient use of power and groundwater and curtailed groundwater withdrawals dramatically but also improved quality of life due to better power supply in nonfarm facilities such as schools, hospitals, and private businesses.
Payment for Ecosystem Services (PES)	To encourage large-scale watershed protection at state level or transition from traditional farming systems to agroforestry	Watershed services provided by the forests in Himachal Pradesh and Madhya Pradesh alone are valued at approximately $34 billion per year (in 2018 US$).[a] The states can sell these services to beneficiaries for payments (i.e., PES) that will be used to compensate projects converting forestland or practices that protect the watershed. The state government realized the value of these services by trading them through the World Bank as carbon credits, which provided important alternatives to government funds for large-scale forest conservation.[b]
Grants or loans	To lower farmers' investment costs and allow more farmers to participate in water management activities	The Indian government approved a total budget of $15.5 million (in 2018 US$) to fund 133 demonstrative recharge projects in 16 Indian states, which has led to the construction of 1,661 artificial recharge structures, and annual water recharge of 55.20 million cubic meters.[c]

Notes: [a.] IIFMB 2006; [b.] CGWB 2016; [c.] DWR 2017.

range of stakeholders, including people living in poverty, than engaging in boom-and-bust cycles—often at the expense of a more sustainable use of natural resources and social cohesion.

Transformative adaptation should be explicitly considered in national budgets, as well as sectoral adaptation and development plans. For example, subsidy, public expenditure, and taxation mechanisms to build long-term resilience in a country's livestock sector (e.g., those affecting feed, vaccinations, land) should be examined to ensure they encourage transformations that promote food security, sustainable resource use, greenhouse gas mitigation, and social equity (Salman et al. 2019).

Coordination must also be improved among governments, funding entities, and research organizations to create and finance transformative pathways. Strengthening connections with the research community can help ensure that the types of crops and livestock production that governments choose to invest in are well-suited to changing climatic conditions.

5.3.3 Fund comprehensive, long-term, multi-phase adaptation

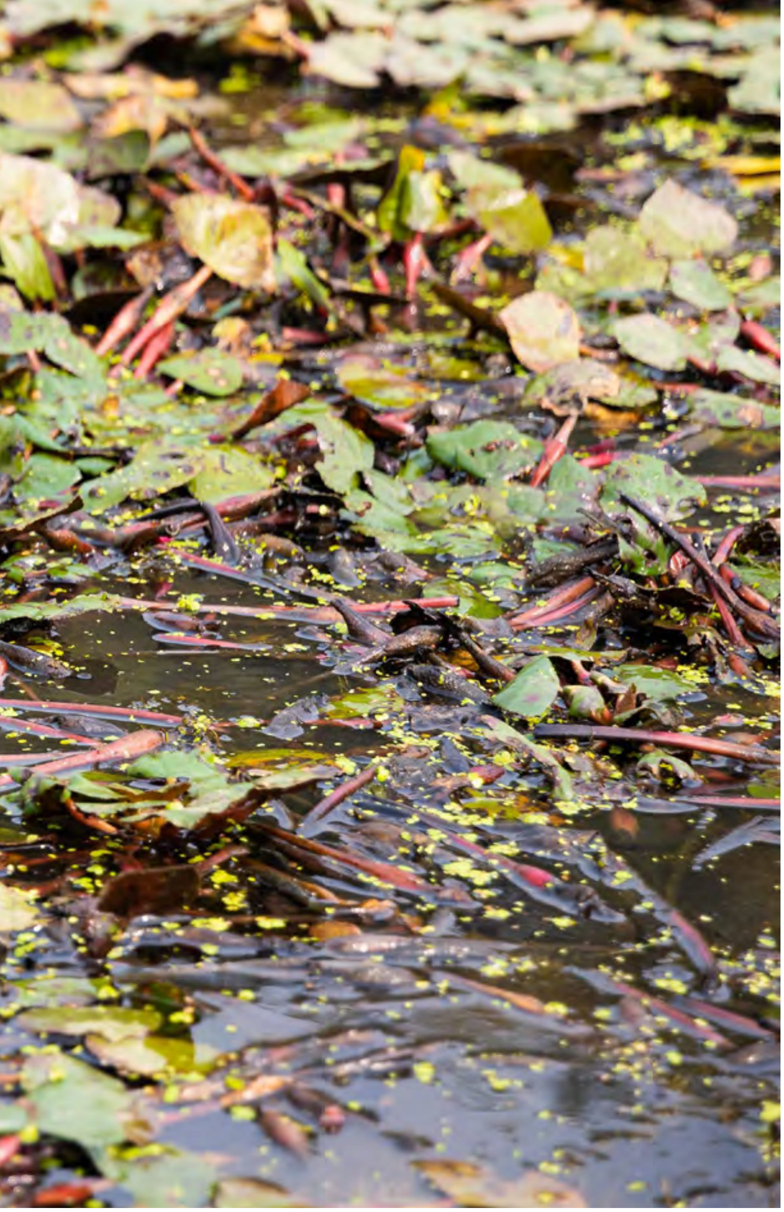
When considering parameters of adaptation interventions, funders need to encourage comprehensive, long-term, multi-phase adaptation programs that recognize the interconnectedness of food systems with other systems—as well as political stability—so that such programs have a chance to be implemented.

On their own, food system shifts tend to occur on medium-to-long-term timelines, as the earlier example of shifting apple production upslope in Himachal Pradesh, India, demonstrated (see Box 1). It takes time to alter fundamental components

of existing systems, as well as markets and institutional arrangements. These shifts will require funding mechanisms that can support more comprehensive, longer-term initiatives than many typical adaptation projects allow. For example, a recently approved Green Climate Fund proposal from Bhutan's Gross National Happiness Commission introduces crop alternatives and climate-resilient irrigation schemes over a 14-year timeframe (GCF 2019).

Longer timelines also afford the opportunity to distribute costs and risks while maintaining flexible adaptation pathways that can evolve as future climate impacts become clearer (Carter et al. 2018). Funders and governments can accommodate longer timeframes by investing in multi-phased projects and programs that span several years or even decades. This will require enhanced collaboration so that projects and programs continuously build off one another. Such long-term, comprehensive initiatives could also be funded by forming multi-funder "ecosystems" of programs, potentially at a regional level, that would take advantage of funders' various strengths and niches.

For example, to build long-term resilience in livestock production, governments, funders, and the private sector should go beyond animal breeding to include investments that improve livestock infrastructure, veterinary and disease prevention services, feed manufacturing and markets, and land rehabilitation mechanisms. Strategically combining these adaptation interventions has the potential for transformative outcomes by fundamentally changing the livestock production system (Salman et al. 2019).



It is also crucial that adaptation funding entities back investments throughout value chains for products that are likely to stand the test of time in a changing climate. Both public and private investment in value chain development and related market policies and programs are needed to enable innovative farmers to produce new products. For example, predictive analytical tools could be co-financed to help producers understand the global market and find better niches in it—and also warn producers when niches are closing due to climate conditions or changing market dynamics.

For example, the switch from coffee to citrus by farmers in some areas of Costa Rica provided a new opportunity for resilient agricultural production. However, processing plants, storage, and export market access are limited, raising the risk that local and domestic markets may quickly become saturated, leading to the waste of excess produce and price declines. Fortunately, private sector actors have invested in a plant that produces orange juice concentrate.

Of particular interest are plant and animal products that can be produced in increasingly hot and dry areas where more traditional options will soon become unsuitable. For example, the economic value of camels for transportation and meat in Mongolia had been declining for decades due to more appealing and economically viable alternatives—but rising consumer demand for milk due to greater awareness of the product's nutritional benefits led local governments to introduce private sector companies that are working with herders to enhance milk production (XinhuaNet 2020). In another example, cactus pear (*Opuntia ficus-indica*) is a crop that can grow on land where everything else fails. A processing plant in Souk Ahras, Algeria, has improved incomes by processing essential oils, pharmaceuticals, juice, jam, and livestock feed made using it (FAO and ICARDA 2017), which is likely to encourage additional production.

Existing financing modalities must be expanded to support transformative approaches to adaptation, particularly in the form of grants rather than loans, which could easily exacerbate the debt crisis. Instruments and tools designed to finance shorter-term, incremental adaptation may not be as useful for financing longer-term, systemic change—for example, insurance schemes that are designed to buffer farmers against occasional weather-linked losses are likely to go bankrupt as impacts intensify and today's extreme events become "the new normal." However, there may be a role for measures such as reducing premiums for actions that help initiate progress along transformative pathways.

Finally, existing adaptation finance windows could be expanded to include transformative adaptation strategies. The renewed focus on loss and damage that is anticipated at COP26 may offer new opportunities to direct funding toward approaches that facilitate averting and minimizing loss and damage.

CHAPTER 6

CONCLUSIONS AND WAY FORWARD

Countries around the world made a commitment to end hunger and to achieve climate-resilient, low-carbon development when they signed on to the Paris Agreement in December 2015 and the 2030 Agenda on Sustainable Development in January 2016.

Since then, there has been a notable increase in the global commitment to scale up climate change adaptation action, including through the Global Commission on Adaptation—fueled, in part, by increasingly dire climate projections brought to light in the IPCC *Global Warming of 1.5°C* report (IPCC 2019) and other analyses, as well as the real devastation being wrought by climate change–induced wildfires, floods, storms, and droughts.

Our understanding of how climate change will push human and natural systems across thresholds, including those that determine the viability of current food systems, has improved markedly. However, the vast majority of adaptation funding is currently allocated to incremental interventions likely to fall short of their goal of preserving key systems despite climate change impacts.

While still not complete, we do have sufficient understanding to begin taking specific steps to fill in knowledge and funding gaps and get on with building the long-term resilience of smallholder farmers and their communities through transformative approaches to adaptation. These include:

1. expanding research and development to make climate risks visible and engaging farmers, herders, and fishers in identifying transformative solutions for building long-term resilience;
2. integrating transformative approaches to adaptation into planning processes; and/or
3. enhancing finance to mobilize funds and resources to accelerate transformative adaptation.

This report has suggested ways in which research organizations, governments, and funding entities can each play a crucial part in building long-term resilience by fostering systemic change where and when it will be needed. Additional research on related topics is needed, which could include the following:

- Further exploration and more detailed mapping of how the private sector can invest in transformative adaptation and harness various types of financial tools and investments (e.g., impact investing) to transform food systems for long-term resilience
- Context-specific assessments of how to plan and implement transformative adaptation solutions and pathways
- Greater understanding of climate change impacts on aquaculture and fisheries and whether, where, and how transformative adaptation might be applied to them

- How consumer tastes and preferences can be tapped into and shifted to make transformative adaptation more economically attractive
- Deeper analysis of how planning for and implementing transformative adaptation approaches can be made more participatory and inclusive to better incorporate the perspectives and address the needs of women, youth, people living in poverty, and other marginalized groups
- Ways global climate and economic scenario planning can be used to map out transformative pathways, including how to build the capacity of national agricultural research systems to engage in long-term planning
- The extent to which transformative approaches to adaptation are mentioned in enhanced NDCs and NAPs, to include case studies of best practices for both

APPENDIX A. DATA AND METHODOLOGY USED FOR THE COFFEE-VANILLA ECONOMIC ANALYSIS

A1 Data and Assumptions

This section presents data details and key assumptions that were used to conduct the cost-benefit analysis presented in Box 3.

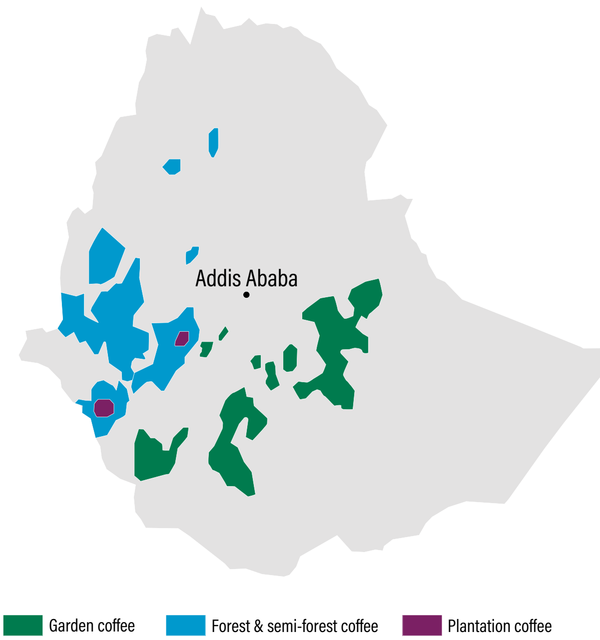
A1.1 Climate Change Impacts on Coffee Production

Ethiopian coffee is produced within specific agroecological zones over numerous political divisions. There are four typical coffee production systems: forest, semi-forest, garden, and plantation coffees.

- *Forest coffee* refers to coffee that grows naturally in primary forests that have not been disturbed or damaged by human interference. Coffee cherries are handpicked, making the productivity of forest coffee the lowest among the four production systems.
- *Semi-forest coffee* grows in forests that are semi-managed by humans (e.g., opening up canopies, clearing weeds) but maintain a minimum of 50 percent canopy cover (Partnerships for Forests n.d.). Unlike for forest coffee, farmers use pruning techniques to increase coffee productivity.
- *Garden coffee* refers to coffee plants that are transplanted to gardens around farmers' homes. These plants might come from nearby forests and are typically interplanted with other crops and fruit trees. Garden coffee is found most frequently in southern Ethiopia, including Sidamo and Harerge/Harrar (Craves 2011).
- *Plantation coffee* is the most intense method of coffee cultivation, where land is cleared and planted with coffee and managed for yield. Farming practices such as pruning, weeding, applying fertilizer, and providing irrigation management are used to improve productivity.

All are mostly found in the tropical rainforest regions of southern and southwestern Ethiopia between altitudes of 1,000 and 2,400 meters above sea level (see Figure A1). These areas currently have the optimum temperature range for growing arabica coffee, between 15 and 24°C.

Figure A1 | Major Arabica Coffee-Growing Areas of Ethiopia



Source: EIAR 2017.

Coffee production in Ethiopia occurs predominantly within traditional farm management systems, with limited use of fertilizers and pesticides. Coffee cultivation and drying are largely unmechanized. Coffee productivity varies greatly across the four production systems. Table A1 summarizes the coffee production areas under the four growing systems as well as the corresponding productivity levels.

The Adaptation Fund (2017) estimated that the mean temperature in Ethiopia will rise between 1.5 and 3°C by the 2050s, taking into account uncertainties in climate modeling. Global warming, along with intensified droughts and uncertain patterns of rainfall, is projected to

Table A1 | Arabica Coffee Production Areas and Productivity Levels in Ethiopia

COFFEE PRODUCTION SYSTEM	TOTAL PRODUCTION AREA (HA)	PRODUCTIVITY (KG/HA)	CONTRIBUTION TO NATIONAL PRODUCTION
Forest coffee	175,000	400	5–10%
Semi-forest coffee	400,000	610	35%
Garden coffee	300,000	700	45%
Plantation coffee	25,000	1,000	10–15%
Total	**900,000**	**Mean=678**	**100%**

have two major impacts on coffee production in Ethiopia: 39–59 percent of productive coffee farms in Ethiopia will be lost by 2050 (Moat et al. 2017); and per-hectare productivity of existing coffee systems will decline due to the rising temperature (USGS and USAID 2012). Craparo et al. (2015) estimated that every 1°C in temperature rise will be associated with a reduction of 137 ± 16.87 kilograms (kg) of coffee production per hectare of land. Hence, the magnitude of per-hectare coffee productivity reduction will depend on how much temperature will actually rise in the future. In other words, the negative impacts of a 1.5°C temperature rise by 2050 on coffee productivity will be lower than those of a 3°C temperature rise. In this study, a 3°C scenario represents a future world with the worst climate impacts on coffee production, whereas a 1.5°C scenario represents a future world with the lowest climate impacts on coffee production. Using this range of temperature projection and assuming a linear rise in annual temperature between 2015 and 2050, we estimated minimum and maximum coffee productivity reductions under 1.5°C and 3°C climate scenarios by 2050, respectively.

A1.2 Coffee Prices

In Ethiopia, local arabica coffee consumption increased, on average, by 11.5 percent between 2011 and 2015, amounting to 56.5 percent of the annual average production for those years, resulting in higher local prices than export prices (EIAR 2017). However, due to a lack of access to local market information, we rely on export data (i.e., total export value and total export volumes) to estimate coffee prices. Statistics between 2005 and 2015 indicate an uptrend in export prices of arabica coffee over time. Coffee prices peaked between 2010 and 2011, following the serious disruptions in coffee production in 2009, which was the second-driest year in Ethiopia since 1971 (Viste et al. 2013). Coffee production stabilized from 2010 onward; however, average arabica coffee prices remained double those prior to the drought year in 2009. Hence, we used the average price of arabica coffee ($3.32/kg) between 2011 and 2015 as a proxy for estimating the total revenues that could be generated from arabica coffee exports in future scenarios. In addition, due to a lack of domestic market information, we assumed that all coffee production in Ethiopia will be used for export to estimate the minimum level of total revenues generated from the coffee sector.

As robusta coffee is not currently grown in Ethiopia, there is no relevant market information available. Therefore, we used the world average price of robusta ($1.96/kg) from Ycharts (2021) to estimate the revenue that could be generated from growing robusta coffee. For the same reason, we assumed an average robusta coffee productivity of 850 kilograms per hectare (kg/ha) in Ethiopia, based on robusta coffee productivity reported in India, approximately 877 kg/ha (Atlas Big n.d.).

A1.3 Coffee Production Costs

Farmers usually need to wait for three to four years from the moment new coffee trees are planted for them to become mature enough to bear fruit. As a perennial crop, a coffee tree will normally produce for approximately 20 to 25 years (Gmünder et al. n.d.). During the full lifecycle of a coffee tree, three categories of costs are incurred by farmers at different stages: establishment costs, maintenance costs before the trees begin producing beans, and maintenance costs once the trees are productive.

Establishment costs refer to the upfront investment costs of planting coffee trees; farmers incur them only in the initial year of establishing a new coffee production system. Maintenance costs before the trees produce beans are incurred in the initial four years of a coffee system establishment when no harvests are reaped. Maintenance costs during the productive period refer to the costs incurred by farmers to maintain production and harvest from the fifth year of new system establishment until the end of the trees' lifecycle.

Due to severe data constraints in Ethiopia regarding coffee production costs, our cost assessment was based on the coffee costs data reported by Thanuja and Singh (2017) for India. Their study provided detailed cost data for both large and small coffee production systems, including itemized costs incurred from establishing new coffee production systems to maintaining the production during the bearing period. We assumed that coffee production in Ethiopia will follow the same cost structure. Based on this cost structure, we then replaced Indian labor costs with local Ethiopian labor cost data published by ILO (2013) to estimate per-hectare fixed costs and material costs associated with establishing new robusta coffee farms in Ethiopia.

On existing arabica coffee farms (i.e., coffee farms with declining coffee production), we assumed that the costs should be similar to those of robusta coffee. More specifically, we assumed that the cost structure of large Indian coffee farms is similar to those of the intensive plantation coffee farming system in Ethiopia; that costs on small Indian coffee farms are similar to those of garden coffee and semi-forest coffee systems in Ethiopia; and that the Ethiopian forest coffee system has a similar cost structure to the small Indian coffee farming system, except that no fertilizer or shade tree costs are applied to the system. In this study, only maintenance costs during the bearing period were considered for different arabica coffee production systems (see Table A2).

A1.4 Vanilla Yields and Costs

Due to a lack of local data, vanilla yields and costs were estimated based on data published by the Indian government (see Table A3).

Table A2 | Per-Hectare Costs of Maintaining Arabica Coffee and Converting to Robusta Coffee Production (US$/ha)

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEARS 6–15
Arabica coffee						
Forest coffee	-	-	-	-	339	339
Semi-forest coffee	-	-	-	-	744	744
Garden coffee	-	-	-	-	1,120	1,120
Plantation coffee	-	-	-	-	1,111	1,111
Robusta coffee	**2,657**	**569**	**619**	**703**	**1,116**	**1,116**

Source: Authors.

Table A3 | Estimated Vanilla Yields and Production Costs

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEARS 6–15
Yield of fresh beans per vine (kg)			0.25	0.5	0.75	1
Total yield per ha (kg)			1,498	2,996	4,495	5,993
Income ($/ha)			11,220	22,440	33,659	44,879
Capital costs ($/ha)	19,086	1,987	2,209			
Maintenance costs ($/ha)				2,406	2,406	2,406
Net income (US$ 2015)			9,010	21,466	32,686	43,906

Note: Abbreviations: kg: kilograms; ha: hectares.

Source: WRI estimation based on data provided by the Department of Agriculture Development and Farmers' Welfare, Government of Kerala, India, via http://keralaagriculture.gov.in/htmle/bankableagriprojects/ph/vanilla.htm. Accessed August 2018.

A1.5 Institutional Climate Adaptation Costs

Institutional adaptation costs incurred to adaptation scenarios are costs arising from developing climate adaptation strategies, increasing the awareness of adaptation risks at the local level, and investing in projects to improve capacity, monitoring, evaluation, and local learning, among others. In principle, adaptation may be autonomous or strategy-specific and will depend on a range of factors, including the level of greenhouse gas emissions anticipated (UNEP 1998). In practice, however, it is often difficult to anticipate what level of adaptation will be needed and effective at the local level when climate change impacts are uncertain.

No information was available on costs related to adaptation projects in Ethiopia specifically targeted to reducing climate change impacts on coffee farms. As an alternative, we reviewed climate-smart integrated rural development projects on the Adaptation Fund's website (https://www.adaptation-fund.org/projects-programmes/) and assumed that adaptation costs associated with climate-smart agriculture in Ethiopia can be used as a proxy for estimating the lower-bound adaptation costs for coffee production. In 2017, the government of Ethiopia requested a total amount of just under $10 million in financing support from the Adaptation Fund for an agricultural adaptation project for a period of 3.5 years (Adaptation Fund 2017). The project targets highly vulnerable smallholder farmers in 14 kebeles (smallest administrative unit of Ethiopia similar to a ward or a neighborhood) and aims to increase ecosystem resilience to climate change and reduce climate risks like drought in Ethiopia. It covers six districts: Oromia; Tigray; Amhara; Harari; Southern Nations, Nationalities and Peoples Regional State; and Dire Dawa. The total area of these districts was then used to calculate the average annual per-hectare costs for each adaptation activity; itemized adaptation costs can be found in Table A4.

Table A4 | Climate-Smart Integrated Rural Development Project Costs

COST COMPONENTS	OBJECTIVE	EXPECTED OUTCOMES	AMOUNT (US$)	COST PER HECTARE PER YEAR ($/HA)
Awareness and ownership of adaptation planning at the local level	Increased awareness, understanding, and ownership of climate risk reduction processes and adaptation planning at all levels; climate-resilient livelihood and water plans; climate-smart agriculture and land-water-forest integration plans	Increased capacity to manage current and future drought risks through improved adaptation planning and sustainable management of agroecological landscapes	367,510	0.0018
Climate-smart agriculture and land-water-forest integration	Climate-smart agriculture implemented at the farm level; integrated watershed management approach used to restore and protect degraded watersheds	Increased capacity to manage current and future drought risks through improved adaptation planning and sustainable management of agroecological landscapes	1,590,227	0.0076
Climate-resilient livelihood diversification	Improved knowledge, understanding, and awareness of livelihood opportunities; increased capacity of target			

Table A4 | Climate-Smart Integrated Rural Development Project Costs (Cont.)

COST COMPONENTS	OBJECTIVE	EXPECTED OUTCOMES	AMOUNT (US$)	COST PER HECTARE PER YEAR ($/HA)
households to participate in climate-resilient, market-oriented enterprises	Increased capacity to manage current and future drought risks through improved adaptation planning and sustainable management of agroecological landscapes	527,371	0.0025	
Capacity building, monitoring, evaluation, and learning	Increased capacity and knowledge transfer; project results monitored and evaluated and lessons captured; results and lessons communicated to key stakeholders and mainstreamed in local planning processes	Increased capacity to manage current and future drought risks through improved adaptation planning and sustainable management of agroecological landscapes	1,799,288	0.0086
Project execution cost			465,405	0.0078
Implementing entity project cycle management fee			501,443	0.0084
Total cost			**5,251,244**	**0.0369**

Source: Adaptation Fund 2017.

ENDNOTES

1. Note that many of the citations included in this section refer to the TACR topical papers on crop research and development (Niles et al. 2020), climate services (Ashley et al. 2020), livestock production (Salman et al. 2019), and water management (Sixt et al. 2021, forthcoming), as well as applications of the TACR framework in Tye and Grinspan (2020) and Ferdinand et al. (2020).

2. *Loss and damage* is the term used to describe impacts of climate change that have not been or cannot be avoided through mitigation and adaptation efforts (Van der Geest and Warner 2015).

3. Since Ethiopia intends to increase coffee production and remain a key coffee exporting country in the future (NPC 2016), the analysis also estimated the potential economic gains of introducing garden coffee in the higher-altitude regions, where climate conditions will become suitable for coffee as temperatures rise. In these areas, introducing home garden coffee (see Appendix A, Section A1.1) will not only help restore the degraded agricultural land by increasing tree shade, but also provide additional cash income, playing an important role during times of food shortage (Linger 2014). These estimates were excluded from the cost-benefit analysis to ensure a fair comparison of the costs and benefits of the three adaptation scenarios.

4. Additionally, if arabica garden coffee were introduced and intercropped with the existing crops located in higher-altitude regions that become suitable for coffee due to temperature rise in the future, this will not only directly contribute to cash incomes of farmers in highland areas, but also serve as an agroforestry practice to diversify and sustain production for increased social, economic, and ecological benefits. The desire for more shade trees could also add value to and thereby incentivize restoration efforts. Assuming that an area of arabica garden coffee equivalent to the size of an unsuitable coffee production area will be intercropped in higher altitudes, this will generate at least another $1.2 billion over the next 35 years on top of the incomes that have been generated from the existing crop systems.

5. Khan, M. Correspondence between the author Tyler Ferdinand, research associate, and Mustafa Ali Khan, team leader SCA-Himalayas, Swiss Agency for Development, New Delhi, India. June 11, 2019.

6. Meaza, H. Correspondence between the author Tyler Ferdinand, research associate, and Hailemariam Meaza, assistant professor, Mekelle University, Tigray, Ethiopia. October 1, 2019.

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ABOUT WORLD RESOURCES INSTITUTE

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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