GLOBAL COMMISSION ON ADAPTATION

DISCUSSION PAPER

FEEDING THE WORLD IN A CHANGING CLIMATE: AN ADAPTATION ROADMAP FOR AGRICULTURE

Executive Summary

The impacts of a warming world are affecting food production in every corner of the globe. From shifting rainfall patterns and growing seasons, to more frequent and extreme droughts and floods, to increasingly severe pest and disease outbreaks among crops and livestock, farming as we know it is under attack.

Globally, agricultural production has fallen by 1-5 percent each decade for the past 30 years, with tropical regions the hardest hit. In 2017, according to the UN Food and Agriculture Organization (FAO), droughts, floods and delayed growing seasons helped trigger food crises in Central America, East and West Africa, and parts of Asia. Yet far worse outcomes are likely ahead for vulnerable food consumers and producers as these climate change impacts intensify and the world's population climbs—if we persist with a business as usual approach.

The implication is clear. The agricultural development community must urgently come together around a comprehensive and accelerated adaptation roadmap for food production acknowledging that major transitions across the agriculture sector will be needed. This report seeks to lay the groundwork for a way forward. It brings together academic research, examples of proven adaptive technologies and practices, and lessons learned from practitioners including government, farming communities and the private sector. It then provides recommendations for the development of new technologies and practices and on how to scale what's already working to drive global climate-resilient transitions. The report focuses on agriculture, primarily in the developing world, recognizing that this is only a part of a larger and more complex set of issues related to food systems and their transformation for sustainability.

The report identifies a range of adaptive farming technologies and practices that are proven to work and suitable for scaling. These include stress tolerant crops and livestock breeds, sustainable forms of farming intensification, and better risk management through innovations like climate information systems and index-linked insurance. As policy makers, farmers, scientists, civil society organizations and others trial these and other adaptation practices around the world, important lessons for success are emerging that should inform future efforts.

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It is critical to consider the social and economic context of farming communities in designing solutions. For example, policymakers have been more successful when they tackle the root causes of climate vulnerability, such as lack of income to invest in adaptive technologies, and empower participation by women, youth, and other especially vulnerable groups.

Collective action is often key to success. In countries ranging from Bangladesh and Cambodia, to Ghana and Uganda, for example, policymakers, communities, scientists and other stakeholders together developed resilience roadmaps suited to a range of future development scenarios. In other countries collective action between governments and the private sector has helped deliver results. In Colombia, for example, the Ministry of Agriculture and rice producers' federation strengthened the sector's resilience by providing farmers with timely climate information to support wise planting decisions.

Given the pressing threat to food security, scaling proven new adaptive technologies is an imperative. Here, gov-

About this paper

This discussion paper presents the main issues to be considered in an adaptation roadmap for agriculture, with a particular focus on developing countries. It explores the following critical questions: What are the principal climate risks to agriculture and the implications of no adaptation? What are the key areas where action is required to advance in the implementation of climate-resilient agriculture practices? What are the emerging lessons from successful adaptation efforts in agriculture? What are the key pathways to scaling up agricultural adaptation? The paper's key recommendations include: 1) promoting climate-resilient and low-emission practices and technologies; 2) expanding digital climate information services; 3) mobilizing innovative finance to leverage public and private sector investments for adaptation; 4) strengthening farmer and consumer organizations and networks; and 5) delivering enabling policies and institutions.

About discussion papers

The Discussion Papers explore some of the key challenges that the Global Commission on Adaptation will address. They contain preliminary research and analysis, and outline potential solutions. They are intended to stimulate timely discussion and to inform ongoing debate on emerging issues. They therefore lay some of the groundwork for the GCA flagship report and its evidence-based narrative about how humanity can continue to progress, despite the impacts of climate change.

These papers reflect the views of the authors and not of the Global Commission on Adaptation or of the Managing Partners to the Commission

Discussion Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues.

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ernments were successful when they provided the right incentives and resources to attract major investment by private sector or international donors, or when they used communications media to spread the message to farmers. Finally, efforts around the world underscore that there is no single silver bullet for success. Instead, adaptation policies, technologies and tools must be tailored to suit each sector, regional or local context, and be designed to help farmers cope with both current and predicted climate change impacts.

To achieve major transitions across the agriculture sector and to replicate promising solutions, on the scale required to address climate change risks and ensure food security, the authors suggest that research and farmers' organizations, the private and public sector, and national and international agencies, pursue an agenda based on the following five building blocks. These recommendations should form the core of future agricultural research, policy, action, and advocacy.

Recommendation 1: Promoting climate-resilient and low-emission practices and technologies. There is urgent need to invest in modern, agile agricultural systems in the developing world, especially to support the most vulnerable smallholder farmers in keeping pace with climate change.

Recommendation 2: Expanding digital climate information services. Getting timely, tailored information to farmers will be crucial to scale their uptake of proven, effective resilience-building tools and techniques. Digital advisory systems, with up-to-date data, and spreading access to digital technology are the answer.

Recommendation 3: Mobilizing innovative finance to leverage public and private sector investments for adaptation. Examples include facilitating public-private partnerships and using public funds to leverage much greater private sector activity.

Recommendation 4: Strengthening farmer and consumer organizations and networks. Considerable resources must be channeled into supporting collective action, building the capacity of farmers and other local organizations, and empowering participation by rural women and youth.

Recommendation 5: Delivering enabling policies and institutions. Governments must step up their focus on delivering policies that support resilient agriculture, in order to meet adaptation targets for the sector, mobilize appropriate farming technologies, tools and practices, and support global food security.

There is urgent need to invest in modern, agile agricultural systems in the developing world, especially to support the most vulnerable smallholder farmers in keeping pace with climate change.

1. What Is at Risk

Changes in climate over the last 30 years are affecting worldwide crop and livestock production, with alarming consequences for present and future food security. Globally, agricultural production has fallen by 1–5 percent per decade as a result of the many impacts triggered by rising global temperatures. Cereal crops in many tropical regions, such as maize and rice, have been hard hit. Furthermore, while warming has benefitted crop production in some temperate regions, even at low (+2 °C) levels of warming, overall agricultural productivity is likely to continue falling across the globe.

Already, this trend is triggering food shortages, affecting many millions of people. According to the Food and Agriculture Organization of the United Nations (FAO) and other agencies, droughts in Central America and East Africa, floods in parts of Asia, and delayed growing seasons in West Africa, were a leading cause of food crises in 2017. With crop yield growth rates per annum already seriously lagging behind what is likely to be required to feed a growing global population, the impacts of climate change pose a major ongoing risk to food security and human development.

1.1 Crops on the Frontline

In the coming decades, temperature shifts will accelerate changes in the distribution and productivity of staple food crops such as maize and rice and, in some tropical regions, major cash crops such as coffee and cocoa. For example, global territory suitable for growing coffee crops may decrease by as much as half by the 2050s, with countries at low latitudes and altitudes, particularly Brazil, India, and Nicaragua hardest hit. Figure 1 shows "hotspot" countries on the frontline of climate impacts for maize, a widely-grown staple food crop. Many countries of sub-Saharan Africa and South Asia are maize hotspots, where substantial yield reductions are projected due to climate change.

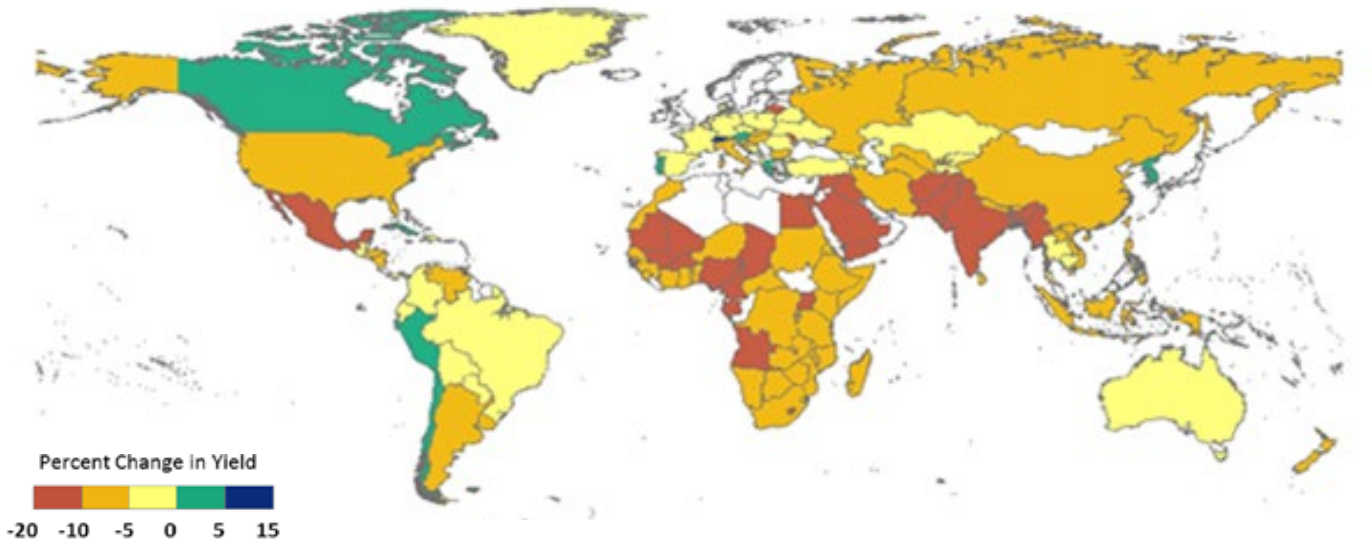
For livestock, predicted impacts include substantial drops in forage availability in large parts of West, East, and Southern Africa and tropical South America and wide-spread negative impacts on forage quality. This, in turn, will impact livestock productivity, with cascading impacts on the incomes and food security of dependent communities.

1.2 Risks from Extreme Events

Farmers worldwide experience climate change, not only as a gradual change in temperature and rainfall but also in the form of more frequent extreme weather events that are harder to prepare for. There is growing evidence that much of the developing world faces rising risks from drought, extreme rainfall, coastal storm surges, and heat waves. The FAO has already pinpointed increased climate variability and extremes as a key driver behind the recent rise in global hunger, and a leading cause of severe food crises.

Figure 2 maps the different hazards facing the global tropics—important food-producing regions housing 1.1 billion people that have low coping capacity for intensifying climate impacts. By the 2050s, large areas of the Sahel, Eastern and Southern Africa, and South Asia will face much greater climate variability, while temperature changes will be a major hazard for Central America, many parts of South-East Asia, and lower latitudes of West and Central Africa. Almost all the countries shown rank at the bottom third of the Global Food Security Index.[2]

FIGURE 1 Climate Change Impact Hotspots for Maize Yields, 2050



Notes: Climate change impacts from 2000 are country averages based on a meta-analysis of 179 studies published since 1984. Countries with maize areas <10,000 hectares are omitted from the analysis. Values shown are percentage yield changes with adaptation.

Source: Aggarwal et al. 2018 (in review).[1]

BOX 1 The Many Impacts of Climate Change on Agriculture

Climate change can affect agricultural production through multiple pathways, including the following:

- Heat stress through temperature increases higher than experienced over millennia of natural selection and a century of crop breeding.
- More frequent extreme weather events such as droughts and floods.
- Changing humidity and rainfall amounts, including shifting rainfall patterns, increased variability, and shifts in the timing and length of growing seasons.
- More frequent and severe occurrence of pests, weeds, and crop and livestock diseases and pathogens.
- Effects on production and nutrition as rising carbon dioxide concentrations boost carbohydrates in some key crops, at the expense of other nutrients needed for healthy diets. As a result, an estimated 122 million more people will be protein deficient by 2050.

1.3 Risks to Human Development

Worldwide, more than 2.5 billion people make their living from farming. In developing countries, the livelihoods of hundreds of millions of farmers are on the front line of climate change, with poor households and women bearing the brunt of the impacts. In the face of climatic uncertainty, farmers often reduce investment in profitable production technologies in favor of protecting crops against catastrophic loss, a choice that sacrifices production and income levels in most years. Women will often make the choice to eat less—in Bangladesh 60 percent of households reported that women skipped meals more than men.

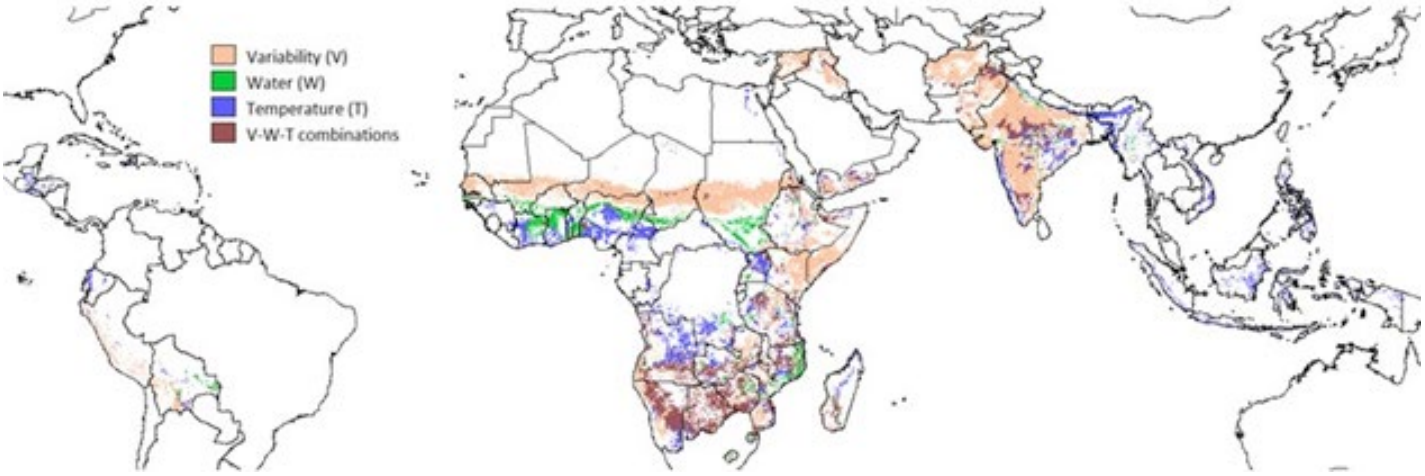
Adaptation needs to take account of the considerable uncertainties surrounding future climate, in order to minimize the risk of maladaptation. Interventions to assist smallholders to adapt can most usefully emphasize "no regret" options, alternatives that are viable regardless of future climatic conditions.

Going beyond the production effects, rising temperatures are affecting the ability of laborers to work in fields, which hits subsistence farming families particularly hard. Rural labor capacity fell by more than 5 percent between 2000 and 2016, with some highly vulnerable regions hard hit (Figure 3).

Beyond rural livelihoods, climate change impacts on agriculture are likely to hinder development progress across the developing world. New FAO data reveal that world hunger rose for the third year in a row in 2017, to a level not seen for a decade, with increasing climate volatility likely playing a part. Today, an estimated 821 million people—that is, one in nine—are undernourished, with the situation worsening in South America and most regions of Africa.

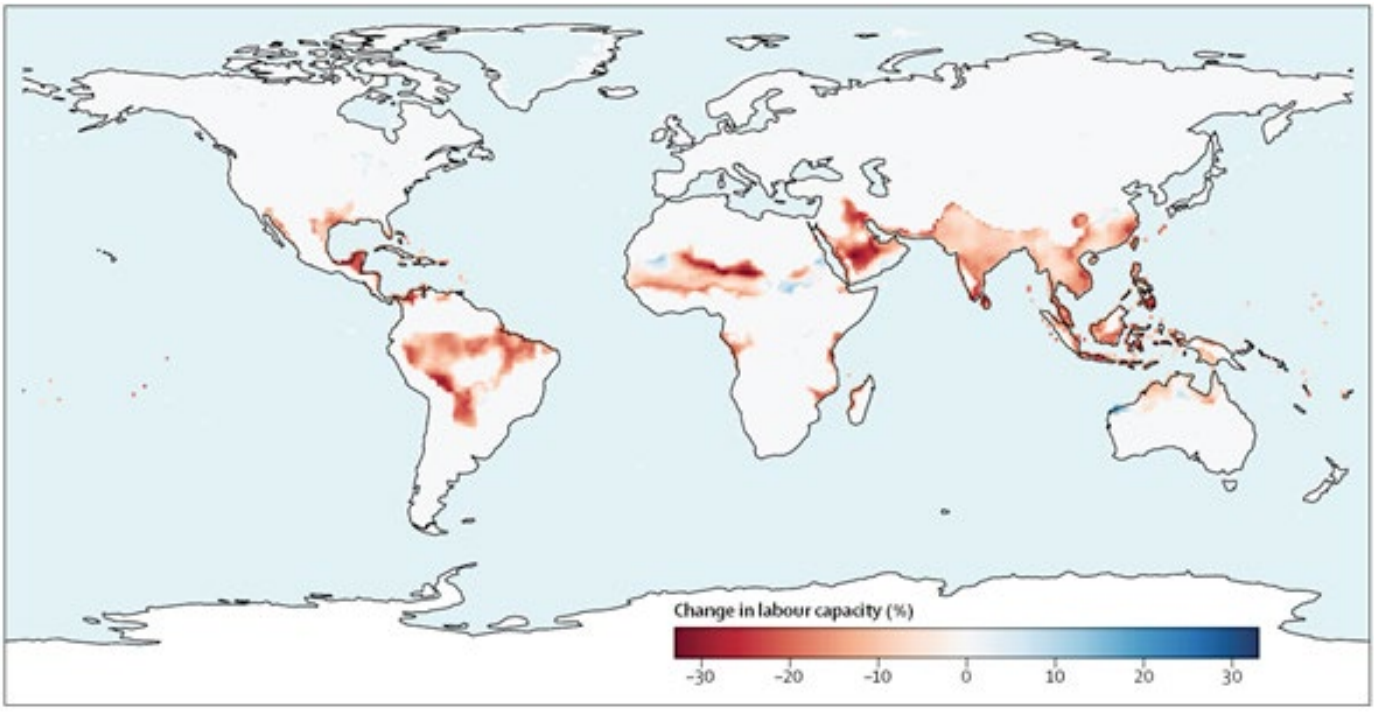
For all these reasons, adapting global farming systems for a warming world must become a global imperative for governments and all players in the agriculture sector. In the next two sections, key areas of opportunity will be explored to adapt agricultural systems to a warming world, as will be the lessons learned from emerging, effective programs and practices on the ground.

FIGURE 2 Range of Climate Change Hazards Facing the Tropics, 2050s



Source: Authors' own calculations.

FIGURE 3 Rural Labor Capacity Loss over the Period 2006–16



Source: Watts et al. 2018.[3]

2. Laying the Groundwork for Adaptation in Agriculture

A warming world puts at risk the progress made in recent decades to reduce undernourishment and improve nutrition and health through government interventions, macroeconomic policies, public investment in science and technology, and rising public finance for agriculture.

A similar all-hands-on-deck push is needed now to prepare the sector for a changing climate. Although, there is neither an updated comprehensive review available nor a documented assessment that articulates the state of adaptation in the agriculture sector, some evidence nevertheless suggests that agricultural-related adaptation responses have been slow and inadequate. For instance, baseline surveys in 21 lower- and middle-income countries by the CGIAR Research Program on Climate Change, Agriculture and Food Security found limited evidence of action on adaptation by smallholder farming.[4]

Despite the endemic development challenges, a wide range of alternatives are already available to assist smallholders to adapt to a warming world. Most usefully, these include "no regret" options that are viable in whatever form future climatic conditions take. As this section describes, laying the groundwork to advance such climate-resilient agriculture practices, worldwide, will require action in the following three key areas:

- Scaling adaptive farming technologies and practices that work;
- Deploying national climate policies and action to drive adaption efforts; and
- Mobilizing finance for large-scale agricultural adaptation activity.

2.1 Scaling Proven Adaptive Technologies and Practices

Agricultural adaptation will require incremental and transformative activity at scales ranging from farming households up to national, regional, and continental agencies.[5,6] Rapidly sowing the seeds for these changes will be vital for the food security of the 8.6 billion people on the planet in 2030, including the 600–700 million smallholder farmers. It will also require concerted action by the entire agricultural development community—research, private sector, farmers' organizations, national and international agencies alike—to scale up viable adaptation options and strengthen enabling policy and institutional environments.

For crops and livestock alike, there are many "no regret" options already in use that focus on adaptability to varying climate and extreme events. For crops, breeding to develop cultivars with traits for adaptability, enhanced nutrient quality, and resilience to varying temperature and precipitation could contribute substantially not only to food security but also to resistance to pests and diseases. In mixed farming systems, integrating crops and livestock can play a similar role.

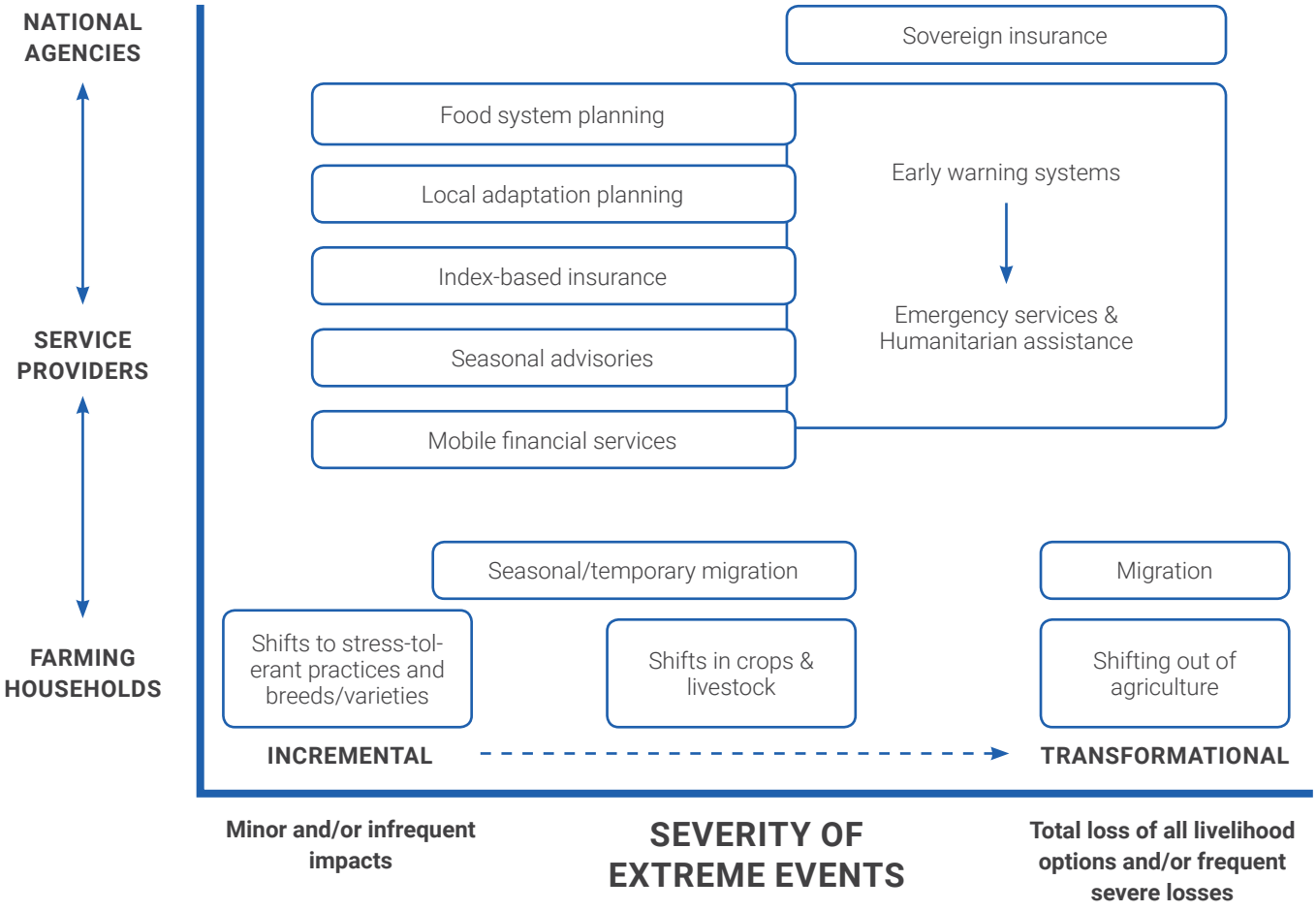
2.1.1 EFFECTIVE OPTIONS FOR SCALING UP

Some of the most promising technologies and practices for scaling are summarized below, as well as showcased in country settings in the following chapter.

New stress-tolerant crop/livestock varieties/breeds. New crop varieties with tolerance to water submergence, drought, high temperature, saline intrusion, and climate-sensitive pests and diseases are one of the simplest technological options available to farmers. However, for many low-potential areas in sub-Saharan Africa, Asia, and Latin America, and for crops of less commercial interest (e.g., many roots, tubers, and pulses), investment in breeding is insufficient to maintain the pace with climate change and to take advantage of 21st century scientific advances. Major investment could create entire new generations of crops with multitrait characteristics capable of withstanding multiple climatic stressors. Investment also should be made to improve access to new materials for smalholder farmers.

Sustainable agricultural intensification. Squeezing more sustainable productivity from land and other resources is widely recognized as a means to enhance food security and adaptation as well as reduce deforestation, water consumption, pesticide and fertilizer use, and GHG emissions.[7] However, current investment in sustainable agriculture research and implementation by agencies, such as the World Bank, falls far short of need. Other constraints on farmers, particularly in developing countries, include lack of access to capital, markets, and information. Figure 5 illustrates the vast potential for applying intensification technologies to close yield gaps in some of the world's poorest and most climate-vulnerable regions.

FIGURE 4 Climate Adaptation Requirements



Source: Author's own elaboration.

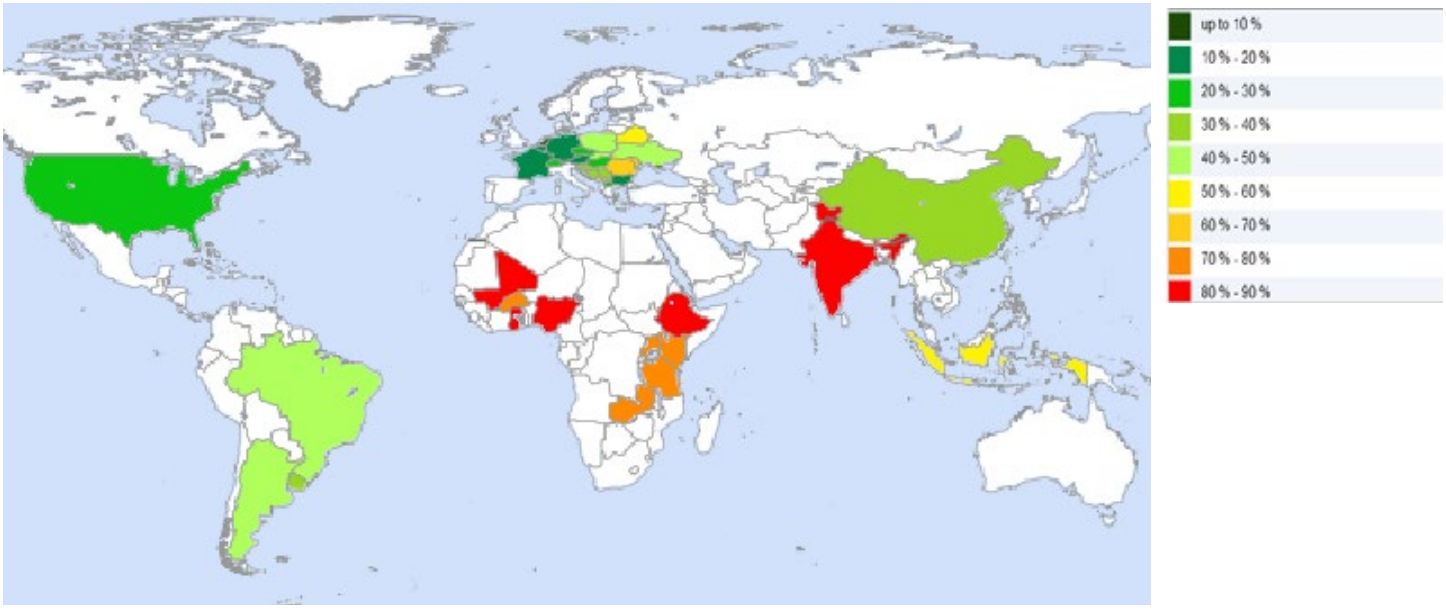
Climate risk management. Providing farmers with timely climate information and/or index-based agricultural insurance can assist them in keeping crops and livestock healthy and livelihoods afloat. Such approaches have been successfully introduced in countries including China, India, Kenya, and Mexico. Other countries are introducing social safety nets that protect the livelihoods of chronically vulnerable and food-insecure populations from the impacts of extreme weather events. Yet investment in such proven approaches is far higher in industrialized countries than in more vulnerable developing regions.

2.1.2 SCALING STRATEGIES FOR ADAPTIVE ACTION

Many resource-effective and climate-resilient agricultural technologies and practices, such as those described above, have been successfully piloted at the local level, although they have not reached impact at scale. Barriers for scaling often relate to farmers' enabling environments; for example, limited access to services, inputs, markets, and capital. They can also be rooted in the absence of supportive national policies and priorities, as well as lack of international finance.

At the national level, this is changing with the 2015 Paris Agreement resulting in many countries placing transformative agriculture adaptation and mitigation policies in their climate action commitments (discussed below). Equally critical, however, will be turning these policies into effective action at the subnational and local levels. Successful climate change adaptation in agriculture is highly context specific[10] and, therefore, there is no fixed package of inter-

FIGURE 5 Yield Gap between Actual and Potential Production for Rainfed Maize



Source: Global Yield Gap Atlas 2018.[8]

ventions or a one-size-fits-all approach. The latter makes it difficult to implement policies conceived at a national level without much understanding of local context. Further, incentivizing farmers' adoption of new practices, such as sustainable intensification, will require removing barriers along production value chains,[11] which often involve various sectors.

Governments that have adopted successful scaling strategies counter these barriers by using a mix of approaches and involving all affected stakeholders across sectors and levels—from local to national and vice versa. For example, national ministries can employ barrier-removing policies to engage the market pull of the private sector in order to reach large numbers of farmers in a cost effective way. To make sure the technology innovations they are bringing to farmers will work, however, government agencies must also engage farming communities to ensure the proposed climate-proofing solutions are locally relevant, affordable, accessible, and culturally acceptible.[12] In turn, successful local initiatives have huge potential to inform decision-makers on how to craft subnational and national policies that meet farmers' needs. Nevertheless, it is important to not underestimate the challenge of organizing and funding extension services able to engage a large number of farmers to implement approporiate and local specific adaptation measures.

BOX 2 Local to National Scaling in Kenya

Kenya's National Appropriated Mitigation Action is a good example of potentially transformative local to national impact. The strategy aims to transform the dairy sector by scaling sustainable fodder and manure management practices through the provision of fiscal support and market links to smallholder cooperatives. If successful, the initiative will sustain 180,000 jobs, increase income and climate resilience alike for more than 600,000 smallholder farmers, and provide nutritional benefits to 3 million consumers.

Source: Dinesh et al. 2018.[9]

2.2 Role of Policies and Institutions

The Paris Agreement offers a not-to-be-missed opportunity to scale climate-resilient farming globally.

Among the 195[13] countries that have signed the agreement, 71 percent include adaptation goals and activities in their nationally determined contributions and 91 percent include agriculture as an adaptation priority. Nationally determined contributions thus have mainstreamed climate change into national—and in some cases, regional—policy agendas. For example, the Central American Agricultural Council has designed a Climate Smart Agriculture Regional Strategy for Central America and Dominican Republic (Box 3).[14]

As governments turn these adaptation plans into policies, they (and international partners providing finance) need to focus on several key areas:

- Guiding local government on agricultural climate risk management strategies for reducing negative impacts on crop yields, income, food security, and nutrition.
- Integrating policies and institutions from the national to the local level to maximize effective adaptation efforts on the ground. Multistakeholder forums and technology innovation platforms involving farmers, governments, and market agents is one useful approach to facilitate cooperation.
- Mainstreaming adaptation measures into national agricultural sector policies, supported by improved dialogue between ministries of environment and agriculture.
- Building the institutional capacity of national ministries and local governments to plan and implement effective adaptation initiatives, and to provide the conditions and incentives for markets and agribusiness to invest in agricultural adaptation measures.
- Encourage new types of institutions and interaction among traditionally disconnected stakeholders, such as public-private partnerships, to assist farmers' access to credit and insurance products that are essential for reducing climate risks.
- Integrating women and youth into capacity-building and adaptation initiatives, recognizing the differential vulnerabilities of women and men (including young women and men), and that women are essential agents of change and innovation.

2.3 Mobilizing Finance

Targeted, high volume finance to scale proven climate-resilient agriculture technologies and practices, such as those showcased above, could have a huge impact on the sector's ability to withstand intensifying climate variability and extreme weather. For example, per capita annual expenditures in weather and climate information services stand at approximately US$2 in sub-Saharan Africa and South Asia, compared with US$16 in Europe.[15] Increasing investment to bring developing countries to the level provided in Europe would prevent an estimated US$1.9 billion in agricultural asset losses.[16]

Current estimates of adaptation costs for agriculture range widely, from US$14 million[17] to US$7.1–7.3 billion[18] and US$3 billion.[19] Whatever the true figure, however, it will take a combination of public, private, and blended finance to transform the sector at the scale required.

The momentum provided by the Paris Agreement will likely

BOX 3 Climate Smart Agriculture: Regional Strategy for Central America and Dominican Republic

The Central American Agricultural Council has decided to provide guidelines for policymakers across the region toward climate action in the agricultural sector with the purpose of aligning efforts toward the United Nations Sustainable Development Goals and the national determined contributions of the United Nations Framework Convention on Climate Change. The methodology used in the Central American Agricultural Council strategy formulation included the use of future-scenario planning tools, where stakeholders involved in the process were able to place themselves in plausible although very diverse scenarios and, from those scenarios, build a robust no-regrets policy framework.

Source: See https://ccafs.cgiar.org/node/55151#.W6jpRPlRepp

steer countries and international actors (e.g., development finance institutions and climate funds) to significantly boost adaptation finance, including for agriculture. In fact, the volume of total public adaptation finance flows allocated to agriculture increased from 11 percent in 2014 to 19 percent in 2016 (US$4 billion), becoming the second most funded sector. Most of these resources came from development finance institutions, particularly multilateral and national, followed by bilateral donors and dedicated climate funds. They were provided in the form of grants, budget expenditure, and low-cost debt. However, while the increase in adaptation finance is a positive sign, more long-term finance for farmers is required to help them invest in those practices and technologies that will cause transformative change in the future.

In addition to international adaptation finance, there is a need to use, much more effectively, existing domestic resources. Currently, tracking domestic climate-related expenditures continues to be a challenge, especially when domestic private and public investments represent the largest share of those in agriculture in developing countries. Hence, existing efforts, such as the Climate Public Expenditures and Institutional Review, are critical to better understand the exact volume of finance invested in agriculture, who is investing it, and how to redirect it to adaptation.

The private sector, meanwhile, has shown willingness to invest in adaptation if there is a clear business case that allows them to align identified risks (and mitigating measures) with their business plans, while generating returns. For instance, Olam, a leading global agribusiness, has developed AtSource, a sustainable sourcing solution designed to promote long-term resilience of agricultural raw materials and food ingredients. The finance industry is also becoming involved, through coalitions such as the Global Adaptation & Resilience Investment Working Group. This private investor-led initiative brings together over 200 private and public investors, bankers, leaders, and other stakeholders to help mobilize action and investment for climate resilience.

Public-private partnerships will also play an important role by leveraging different sources of capital to seize adaptation opportunities. Blended finance, which allows public capital to de-risk private investments, is emerging as one key route forward. For instance, Moringa, which offers private equity for sustainable agroforestry, is building the environmental and social resilience of land use, while generating financial returns for its investors and local communities. Using another model, the World Bank's Integrated Modern Agriculture Development Project[20] directs green bond proceeds to promote sustainable and climate-resilient agriculture in 33 counties and districts.

3. Emerging Lessons from Successful Adaptation Efforts in Agriculture

As the world lays the groundwork described above for making progress toward the adaptation goal set out in the Paris Agreement, it is useful to take stock of emerging lessons for success in agriculture. These lessons can inform policymakers, farmers, civil society organizations, and businesses as they seek to design and implement solutions at scale within the urgent timeframe required. They include the following:

(i) A shared vision of the future of farming helps navigate uncertainty

The planning of adaptation actions in agriculture inevitably occurs against a backdrop of uncertainty in terms of future climate changes and development pathways alike. Developing a shared vision on the future of farming among policymakers, communities, scientists, and other stakeholders can lead to resilient policies and programs that will take into account plausible development scenarios. Participatory approaches have been used to design such policies and programs in several regions.

Case 1: Scenario Guided Climate-Resilient Policy Development in Nine Countries

In Bangladesh, Burkina Faso, Cambodia, Colombia, Costa Rica, Ghana, Honduras, Tanzania, and Uganda, policymakers are using future scenarios, developed through participatory efforts by scientists and other stakeholders, to strengthen policies in the face of climate change impacts.[21] These scenarios offer alternatives of what the future might hold, which help policymakers design robust adaptation policies and plans that will work in a range of future climates and development settings. Cambodia's Climate Change Priorities Action

Plan for Agriculture, Forestry and Fisheries 2016–2020 is a national example of this approach.

(ii) Collective actions help overcome barriers

When the agricultural development sector bands together to help rural communities make their livelihoods more climate resilient,[22] change happens. Governments and the private sector bring different advantages to the table that can help overcome the economic, social, technical, and capacity constraints facing farmers.

Case 2: Rice Producers' Federation in Colombia Benefits from Big Data Analysis

In Colombia, the Ministry of Agriculture and Rural Development, the International Center for Tropical Agriculture (CIAT), and the rice producers' federation (FEDEARROZ), made an alliance to strengthen the rice sector's resilience to climate variability and change. Rice producers lacked climate information to support their planting decisions, so CIAT analyzed historical measurements of climate, yields, and farming practices, which were gathered and filed away by FEDEARROZ using advanced algorithms to identify patterns which align with weather records. As a result, CIAT issued recommendations to farmers not to plant in the Cordoba region, which prevented 1,800 hectares of rice crop from being lost and saved US$3.5 million in input costs. FEDEARROZ now systematically incorporates agro-climatic information produced by CIAT in all farm extension systems, and the Ministry of Agriculture and Rural Development is helping expand this initiative to other crops through a web-based platform.

(iii) Adaptation actions need to tackle the root causes of risks and vulnerabilities

Only by tackling the social, economic, and cultural root causes of climate risks and vulnerabilities affecting farming communities can adaptation solutions be sustainable over time.[23] For example, in Case 3, one of the root causes of vulnerability among communities in Bangladesh, the Philippines, and Vietnam was dependence on pump irrigation for rice production.

Case 3: Alternate Wetting and Drying in Rice Reduces Costs and Addresses Water Scarcity

Rice farmers often depend on pump irrigation to meet the water needs of production. This creates additional costs that, in turn, reduce disposable incomes and make producers more vulnerable to climate change impacts. The solution employed in several countries, including Vietnam, the Philippines, and Bangladesh, is a water-saving practice of alternately wetting and drying rice, reducing water use in crop production by 15–40 percent. This method can prevent or mitigate drought impacts while reducing the costs of pump irrigation which, in turn, increases farmers' disposable income and reduces their vulnerability.

(iv) Food system reform can empower women, youth, and other marginalized groups

Women's empowerment plays a key role not only in family nutritional outcomes, but in the entire upstream food system, including household consumption and waste. In some OECD countries, women make over 80 percent of consumption decisions. They also supply almost 50 percent of the world's agricultural labor force, and more so if their informal food production, processing, and marketing activities are taken into account. Yet, they tend to have less income and access to agricultural information and extension services than men, with the result that their production is generally lower, and resilience to climate shocks more limited. Similarly, the soaring youth population in developing countries poses enormous challenges for climate resilience. Africa's youth population (aged 15–24) of 226 million is estimated to double by 2055. Seven in 10 young Africans work in agriculture, with little access to finance and services.

Adaptive farm practices and technologies can provide enormous benefits for women— who are just as likely as men, if not more so, to adopt them—and for youth. Access to cell phones, radio, and other communications technologies promotes resilience, while participatory community-based

approaches have a proven track record in empowering women and youth to use adaptation practices to establish productive livelihoods.

Case 4. Empowering Women and Youth at the Community Level

A project with youth and women's groups in Kenya introduced labor- and energy-saving irrigation and increased yield and crop diversity. A community finance fund reduced the number of households experiencing food insecurity and increased school enrollments, while expanding small-scale trade and purchases of farm inputs. In Nepal, a solar-irrigation project decreased the labor for women in watering fields, improved water use, and increased harvests from one to three harvests a year.[24]

(v) Approaches to leapfrog learning curves are key

Lesson learning based on experience can be slow and inadequate, given the growing urgency of spreading resilient farm practices to protect food security.[25] By using new communications approaches to knowledge sharing that quickly reach wide audiences, countries can speed the adoption of adaptation successes.

Case 5: Leapfrogging the Learning Curve through Reality TV

Shamba Shape Up, a reality TV show in East Africa (Kenya, Tanzania, and Uganda), guides producers to give their farms a "make-over". Scientists have been mainstreaming climate adaptation actions through the show, providing guidance on farm-level interventions. This initiative replaces traditional knowledge sharing approaches and saves resources and time. The show reached an average monthly viewership of over 9 million in 2014, and an estimated 42 percent of viewers adopted recommended practices, boosting maize and dairy production by US$24 million in Kenya. Scientists and development partners are now expanding these efforts by linking Shamba Shape Up to mobile, SMS, and Internet services.

(vi) Meeting short- and long-term priorities alike

Since climate change impacts facing farmers are short term (changes in rainfall) as well as long term (changes in growing seasons), adaptation interventions must balance both needs.[26] For example, in Case 6, intercropping coffee and bananas serves this purpose.

Case 6: Climate-Smart Banana-Coffee Intercrop Systems in East Africa

Coffee systems in East Africa are increasingly vulnerable to the impacts of climate change, including rising temperatures. Intercropping bananas with coffee can help mitigate these risks in the long term by increasing the resilience of the system. Simultaneously, in the short term, banana cultivation can help increase revenue by over 50 percent through banana sales.[27] The win-win system meets the short- and long-term priorities of farming communities and is being scaled across East African countries.

(vii) Adaptation actions to suit context

Given that there are no silver bullets for adaptation actions in agriculture, it is essential to identify measures that work in any given farming context.[28] Various tools and guidance are already available to support farmers in selecting interventions that maximize benefits and reduce the risk of maladaptation. For example, while Case 6 presents a practice that involves sustainable intensification efforts suited to coffee growing in East Africa, Case 7 showcases diversification through the introduction of aquaculture into crop smallholdings.

Case 7: Smallholder Aquaculture in Northern Province, Zambia

In northern Zambia, smallholder farmers are diversifying into fish farming to enhance climate resilience and improve productivity.[29] They are introducing small species, which are rich in micronutrients and well-suited to local wetland conditions, into mixed systems with tilapia to generate income. The ponds are operated with low input costs.

(viii) Realizing benefits at scale

While many promising adaptation actions are emerging in agriculture, not all are scalable, and many do not grow beyond pilot projects. Key factors for achieving scale are a conducive enabling environment, coupled with appropriate incentives, capacity, and resources. In Case 8, climate-resilient maize varieties spread across sub-Saharan Africa due to a long-term resourcing strategy, combined with capacity development and incentives that boosted farmer uptake.

Case 8: Stress-Tolerant Varieties Scaled in Africa

Over the past decade, the Bill & Melinda Gates Foundation and the U.S. Agency for International Aid have invested heavily in stress-tolerant maize for Africa, thus improving breeding, strengthening the seed sector, and reducing bottlenecks associated with adoption. As a result, over 200 stress-tolerant maize varieties have been released across 13 countries, with the potential to generate US$360 million to US$590 million over seven years.[30] Farm trials have demonstrated that climate-resilient maize varieties produce 20 percent more crop than current commercial varieties in low-yield environments, and double in severe stress environments, such as the El Niño event of 2015–16.[31]

(ix) Tracking progress toward adaptation goals

Tracking progress toward goals is a crucial aspect of any effective adaptation strategy. In the agricultural sector, FAO's *Tracking Adaptation in Agricultural Sectors: Climate Change Adaptation Indicators*[32] provides guidance that can be adapted to context-specific needs. For example, companies have used the guidance to design approaches to monitor progress toward supply chain adaptation goals.

Case 9: Measuring Progress toward Private Sector Agricultural Adaptation Goals

Member companies of the World Business Council for Sustainable Development are committed to strengthen the climate resilience of agricultural landscapes and farming communities.[33] Effective monitoring of progress toward this goal is crucial to manage progress. To this end, the CGIAR Research Program on Climate Change, Agriculture and Food Security reviewed the monitoring efforts of individual companies, as well as collective progress toward the global goal. Based on the gaps identified, an indicators framework has been proposed to measure progress on an ongoing basis.

4. Recommendations: a roadmap for transforming food systems in a changing climate

There is a growing recognition that incremental adaptation will be inadequate to deal with rapid shifts and tipping points for food production under global change. Instead, major transitions across the agriculture sector will be needed. The challenge is complex and the time is short, but as presented in this paper, opportunities exist in terms of technologies and practices, policies and institutions, innovative finance, and scaling approaches. In addition, there are many successful cases in the field to learn from.

To meet this challenge, it is believed that the agricultural community, including the research community, private and public sector, farmers' organizations, and national and international agencies, should adopt the following five pathways to support global climate resilience and food security (Figure 6). It is suggested that this agenda should form the core of future agricultural research, action, and advocacy.

(i) Promoting climate-resilient and low-emission practices and technologies:

Continuing development of new technologies and practices will be crucial. For example, increasingly unpredictable and variable weather will require technologies that deal with multiple stresses in the same location, such as drought, floods, and heat. In addition, estimates suggest we only have technologies to deal with 20–40 percent of the emissions reductions from farming required.[34] Research, innovation, and technology transfer systems will need to be highly effective, with researchers and extension officers working seamlessly with all stakeholders crucial for scaling. "No

regrets" investments in agricultural development will also bring critical co-benefits for reducing poverty and inequality in a way that also builds the resilience of the most vulnerable populations to the expected and unexpected challenges posed by climate change.

Recommendation #1

There is urgent need to invest in the modernization of agricultural systems in the developing world, especially for smallholder farming systems where yield gaps are large. For example, it must be ensured that animal and crop breeding systems are sufficiently agile to respond to the needs of the most vulnerable farmers to keep pace with climate change. This will require a rapid cycle of breeding that helps:

- generate higher rates of genetic gain by accelerating the development of varieties demanded by farmers, processors and consumers; and
- increase the rate of varietal turnover in farmers' fields to deliver these stress-tolerant varieties and the associated productivity gains into farmers' fields.

(ii) Expanding digital climate information services:

Agriculture and allied sectors have lagged behind in the use of information and communications technologies. This needs to change, ushering in the digital era in food systems in order to generate efficiency gains for farmers, foster two-way agricultural advisory systems that are climate-informed, and facilitate adaptive safety nets, such as index-based insurance, that can be made more efficient through the use of digital platforms.

Recommendation #2

Knowledge, tailored to the needs of farmers and other value chain actors, will be crucial to scale their uptake of proven and effective resilience-building tools and techniques. Digital advisory systems that allow multiway flow of tailored information are the solution, founded on better data and much enhanced access to digital technology.

(iii) Mobilizing innovative finance to leverage public and private sector investments for adaptation:

Innovative models for financing are essential to achieve resilient food systems as current levels of financing are totally inadequate. New skills in research and development must also be honed in to link with banking, credit, investment, and insurance communities, as well as to design schemes that incentivize investment and de-risk agriculture. This is particularly urgent given the increasingly unpredictable weather. Incentivizing private investment will require governments to redirect subsidies to address the positive externalities of adaptation investments and to integrate private risk considerations into national adaptation planning.

Recommendation #3

Much greater attention must be paid to how agriculture and value chains can be de-risked in the face of increasing climate variability, and how public funds can leverage exponential increases in private-sector activity.

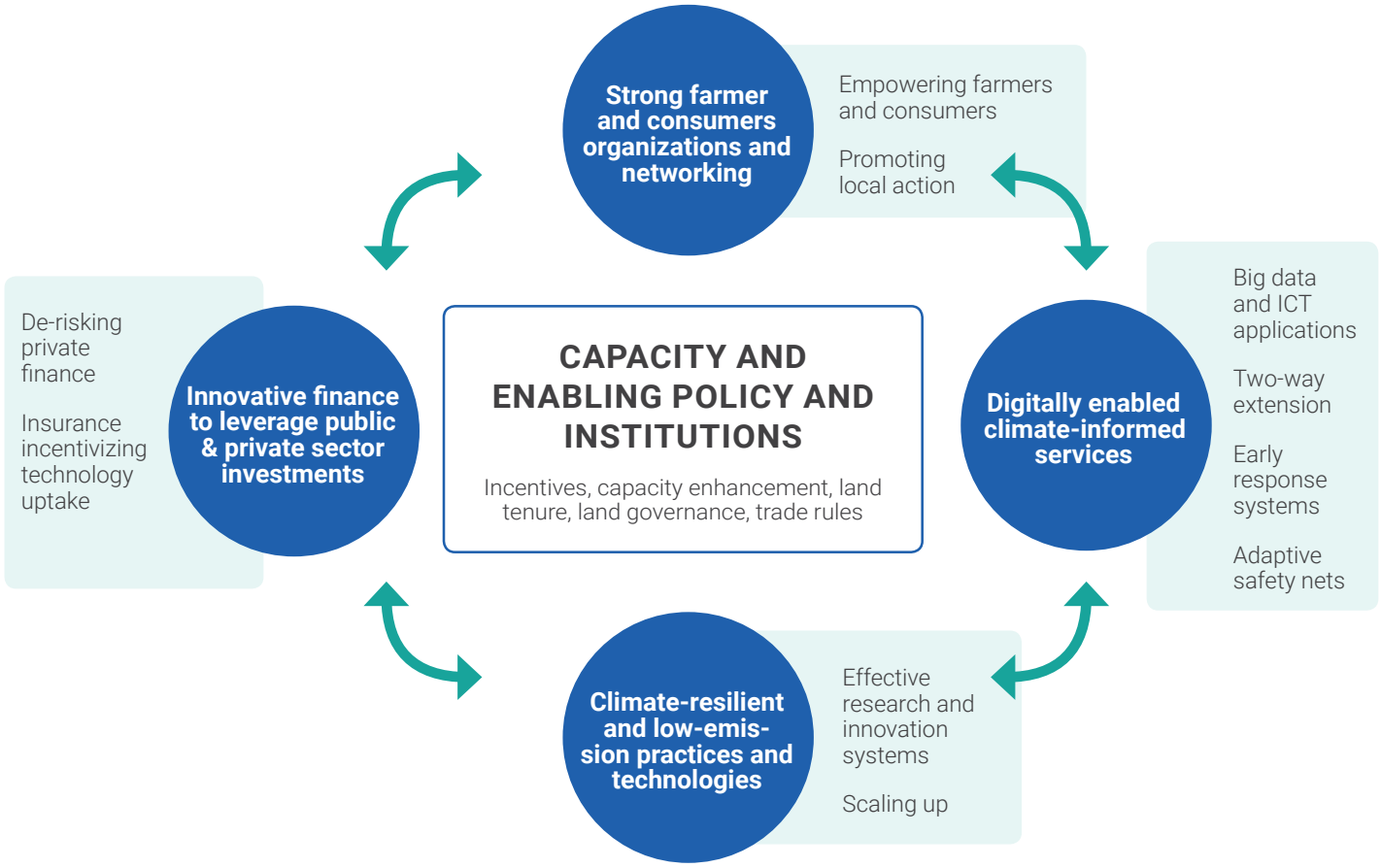
(iv) Strengthening farmer and consumer organizations and networks:

For food systems transformation, strengthening farmer and consumer organizations and their networks will be essential to drive demand-driven solutions. Research in Australia has demonstrated how farmers' networks have been instrumental in climate change adaptation. Similarly, governments should expand effective participatory, community-based approaches that target the priorities of women and youth, increase access to and control of resources, and promote collective decision-making at all levels.

Recommendation #4

Considerable resources need to go toward supporting collective action, building the capacity of farmers and other local organizations, as well as empowering rural women and youth.

FIGURE 6 Five Building Blocks to Climate Change Resilient Agriculture



Source: Author's own elaboration.

(v) Delivering enabling policies and institutions:

This element is fundamental to the success of all the other recommendations. Governments must pursue, urgently, initiatives that create a conducive enabling environment for agricultural development by encouraging innovation, investment, and action. To drive effective adaptation, policies and incentives must also encompass related issues and barriers such as digital infrastructure, ease of doing business, and land tenure. Delivering these policies will require enhancing human capacity at all governance levels.

Recommendation #5

Governments must step up their focus on policies that work for food systems and agriculture. Without such a conducive policy environment, it is unlikely that agricultural adaptation targets will be achieved. Instead, appropriate agricultural technologies, tools, and practices will "remain on the shelf" and food security prospects for the world will worsen.

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