TRANSFORMING FOOD SYSTEMS UNDER A CHANGING CLIMATE

Actions to **Transform Food Systems** Under Climate Change

Authors

PANEL OF EXPERTS

Chair: Achim Steiner, Administrator, United Nations Development Programme (UNDP)

Grethel Aguilar, Acting Director General, International Union for Conservation of Nature (IUCN)

Khalid Bomba, Chief Executive Officer, Ethiopian Agricultural Transformation Agency

Juan Pablo Bonilla, Manager, Sustainability and Climate Change Department, Inter-American Development Bank (IADB)

Andrew Campbell, Chief Executive Officer, Australian Centre for International Agricultural Research (ACIAR)

Ruben Echeverria, Director General Emeritus, International Center for Tropical Agriculture (CIAT)

Rikin Gandhi, Co-Founder & Executive Director, Digital Green

Connie Hedegaard, Chair of the Board, CONCITO and KR Foundation

Diane Holdorf, Managing Director, Food & Nature, World Business Council for Sustainable Development (WBCSD)

Naoko Ishii, Chief Executive Officer, Global Environment Facility (GEF)

Ambassador Kenneth M. Quinn, Former President, World Food Prize Foundation

Bas Ruter, Director of Sustainability, Rabobank

Ishmael Sunga, Chief Executive Officer, Southern African Confederation of Agricultural Unions (SACAU)

Pavan Sukhdev, Founder & CEO, GIST Advisory

Sunny Verghese, Chief Executive Officer and Co-Founder, Olam International

Juergen Voegele, Vice President for Sustainable Development, World Bank Group

Paul Winters, Associate Vice-President of the Strategy and Knowledge Department, International Fund for Agricultural Development (IFAD)

ADVISORY GROUP

Astrid Agostini, Coordinator, REDD+/National Forest Monitoring, FAO

Tim Benton, Dean of Strategic Research Initiatives, University of Leeds, and Research Director, Environment & Resources, Chatham House

Sam Bickersteth, Chief Executive, Opportunity International

James Birch, Senior Programme Officer in Government Relations, Bill and Melinda Gates Foundation (BMGF)

David Howlett, Head of Policy, Global Resilience Partnership (GRP)

Ueli Mauderli, Policy Advisor, Agriculture and Food Security, Federal Department of Foreign Affairs, Swiss Agency for Development and Cooperation (SDC)

Gerald Nelson, Professor Emeritus, University of Illinois at Urbana–Champaign (UIUC)

Anand Patwardhan, Advisor, Global Commission on Adaptation (GCA)

Janie Rioux, Agriculture and Food Security Senior Specialist, Division of Mitigation and Adaptation, Green Climate Fund (GCF)

Tony Siantonas, Climate-Smart Agriculture Director, WBCSD

Charles Spillane, Director of Ryan Institute, National University of Ireland Galway

Jonathan Wadsworth, Lead Climate Change Specialist, World Bank Group

RESEARCH TEAM | CGIAR RESEARCH PROGRAM ON CLIMATE CHANGE, AGRICULTURE AND FOOD SECURITY (CCAFS)

Bruce Campbell, Dhanush Dinesh, Sophia Huyer, Andrew Jarvis, Ana Maria Loboguerrero Rodriguez, Alberto Millan, Philip Thornton, Lini Wollenberg, Stephen Zebiak

PRODUCTION MANAGER: Marissa Van Epp

DESIGNER: Carni Klirs, Graphicacy

To cite this report:

Steiner A, Aguilar G, Bomba K, Bonilla JP, Campbell A, Echeverria R, Gandhi R, Hedegaard C, Holdorf D, Ishii N, Quinn K, Ruter B, Sunga I, Sukhdev P, Verghese S, Voegele J, Winters P, Campbell B, Dinesh D, Huyer S, Jarvis A, Loboguerrero Rodriguez AM, Millan A, Thornton P, Wollenberg L, Zebiak S. 2020. Actions to transform food systems under climate change. Wageningen, The Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Acknowledgments

The Transforming Food Systems Under a Changing Climate initiative began with work packages on five key areas, each of which produced a paper to inform this report. The papers, listed below with their authors, are available at www.transformingfoodsystems.com

Adaptation and development pathways for different types of farmers: Lindsay C Stringer (University of Leeds), Evan DG Fraser (University of Guelph), David Harris (International Crops Research Institute for the Semi-Arid Tropics), Christopher Lyon (University of Leeds), Laura Pereira (University of London), Caroline FM Ward (University of Leeds), Elisabeth Simelton (World Agroforestry)

Transforming food systems under climate change: Local to global policy as a catalyst for change: Tonya Rawe (CARE International), Marta Antonelli (Barilla Center for Food & Nutrition Foundation; Euro-Mediterranean Centre on Climate Change), Allison Chatrchyan (Cornell Institute for Climate Smart Solutions; Cornell University), Terry Clayton (Red Plough International), Jessica Fanzo (John Hopkins Berman Institute of Bioethics), Julian Gonsalves (International Institute of Rural Reconstruction), Alan Matthews (Trinity College Dublin), Danielle Nierenberg (Food Tank), Monika Zurek (University of Oxford)

Changing diets and transforming food systems: Sonja Vermeulen (CGIAR System Organization), Toby Park (Behavioural Insights Team), Colin K Khoury (CIAT), Jonathan Mockshell (CIAT), Christophe Béné (CIAT), Huong Trinh Thi (CIAT; Thuongmai University), Brent Heard (University of Michigan), Bee Wilson (independent journalist)

Innovation can accelerate the transition towards a sustainable food system: Mario Herrero (Commonwealth Scientific and Industrial Research Organisation—CSIRO), Philip Thornton (CCAFS), Daniel Mason-D'Croz (CSIRO), Jeda Palmer (CSIRO), Tim Benton (Chatham House), Benjamin Bodirsky (Potsdam Institute for Climate Impact Research - PIK), Jessica Bogard (CSIRO), Andrew Hall (CSIRO), Bernice Lee (Chatham House), Karine Nyborg (University of Oslo), Prajal Pradhan (PIK), Graham Bonnett (CSIRO), Brett Bryan (Deakin University), Bruce Campbell (CCAFS), Svend Christensen (University of Copenhagen), Michael Clark (University of Oxford), Mathew Cook (CSIRO), Imke J. M. de Boer (Wageningen University and Research—WUR), Chris Downs (CSIRO), Kanar Dizyee (CSIRO), Christian Folberth (International Institute for Applied Systems Analysis—IIASA), Cecile Godde (CSIRO), James Gerber (University of Minnesota), Michael Grundy (CSIRO), Petr Havlik, Andrew Jarvis (CCAFS), Richard King (Chatham House), Ana Maria Loboguerrero (CCAFS), Mauricio Lopes (IIASA), C. Lynne McIntyre (CSIRO), Rosamond Naylor (Stanford University), Javier Navarro (CSIRO), Michael Obersteiner (IIASA), Alejandro Parodi (WUR), Mark Peoples (CSIRO), Ilje Pikaar (The University of Queensland), Alexander Popp (PIK), Johan Rockström (PIK, Universität Potsdam), Michael Robertson (CSIRO), Pete Smith (University of Aberdeen), Elke Stehfest (PBL Netherlands Environmental Assessment Agency), Steve Swain (CSIRO), Hugo Valin (IIASA), Mark van Wijk (International Livestock Research Institute), Hannah H. E. van Zanten (WUR), Sonja Vermeulen (CGIAR System Organization), Joost Vervoort (Utrecht University), Paul West (University of Minnesota)

Financing the transformation of food systems under a changing climate: Alberto Millan (CCAFS), Benhan Limketkai (KOIS Invest), Serena Guarnaschelli (KOIS Invest)

The authors would additionally like to thank the following individuals for their contributions to the report:

Pramod Aggarwal (CCAFS), Lucia Aguirre Sanchez (Rare), Ashesh Ambasta (ITC), Mohammed Bakarr (GEF), Manish Bapna (World Resources Institute), Erin Billman (Science Based Targets Network), Osana Bonilla (CCAFS), Andrew Bovarnick (UNDP), Chris Brown (Olam International), Gabriela Burian (Bayer), Mercedes Bustamante (Universidade de Brasília), Paula Caballero (Rare), Laura Cramer (CCAFS), Jonathan Davies (IUCN), Paul Desanker (United Nations Framework Convention on Climate Change), Ntiokam Divine (Climate Smart Agriculture Youth Network), Jamison Ervin (UNDP), Gustavo Fonseca (GEF), Ellen Franzenburg (World Food Prize Foundation), Susan Gardner (UNEP), Jim Hansen (Columbia University), Charlotte Hebebrand (International Fertilizer Association), Arun Khatri-Chhetri (CCAFS), Chinwe Ifejika Speranza (University of Bern), Gernot Laganda (United Nations World Food Programme), Jakob Lave (Danish Agriculture and Food Council), Anne Lawaetz Arhnung (Danish Agriculture and Food Council), Mark Lundy (CIAT), John Lynam (CIAT), Chandra Manalu (UNEP), Deissy Martínez Baron (CCAFS), Hayden Montgomery (Global Research Alliance on Agricultural Greenhouse Gases), David Nabarro (Food Systems Dialogues), Deon Nel (GRP), Niels Peter Noerring (Danish Agriculture and Food Council), Midori Paxton (UNDP), Tim Payn (Scion), Cristián Samper (Wildlife Conservation Society), Leocadio Sebastian (CCAFS), Hege Skarrud (Spire), Wiebe Smit (CCAFS), Máximo Torero (FAO), Dawit Solomon (CCAFS), Meghna Usharani Ravishankar (World Food Prize Foundation), Ben Valk (Rabobank), Maria Elena Varas (World Economic Forum), Alain Vidal (WBCSD), Luisa Volpe (World Farmers' Organisation), Haoliang Xu (UNDP), and Robert Zougmoré (CCAFS).

Contents

Figures

Tables

Boxes

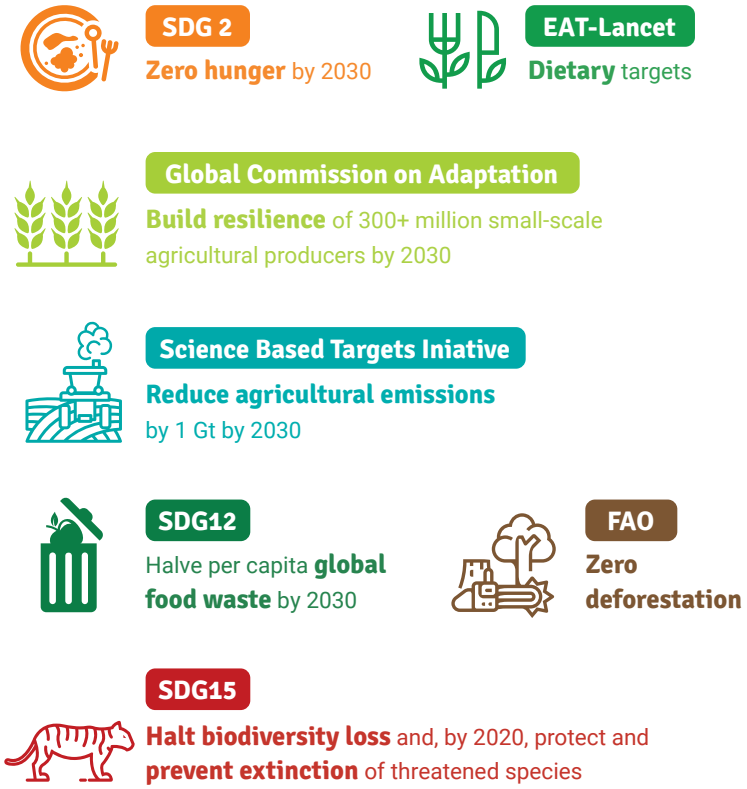
SUMMARY

Putting the food system on a new trajectory

Our food systems are failing us. This is the overarching message from the wealth of literature on food systems.[1] Analysis by Bene and colleagues finds that this growing body of literature focuses on four main types of failures: food systems' inability (i) to produce greater quantities of food to feed a growing world population, (ii) to meet nutritional needs, and (iii) to benefit everyone equally and equitably, with both over- and underconsumption rife in current food systems, plus (iv) the negative impacts of food systems on the environment and natural resources.[1] Last but far from least, climate change is increasingly having severe negative impacts on food systems, while food systems themselves are part of the problem through direct and indirect emissions.[2] Our score for the global food system: cause for grave concern.

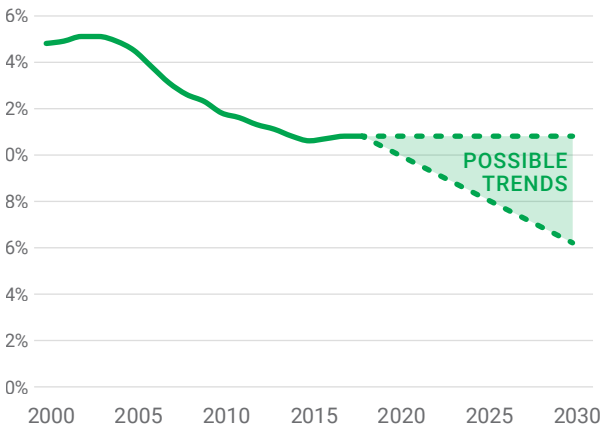
To address the challenges, numerous goals and targets have been proposed (some are shown in Figure A) and many initiatives have been established.

FIGURE A. Some examples of food system targets[3,4,5]



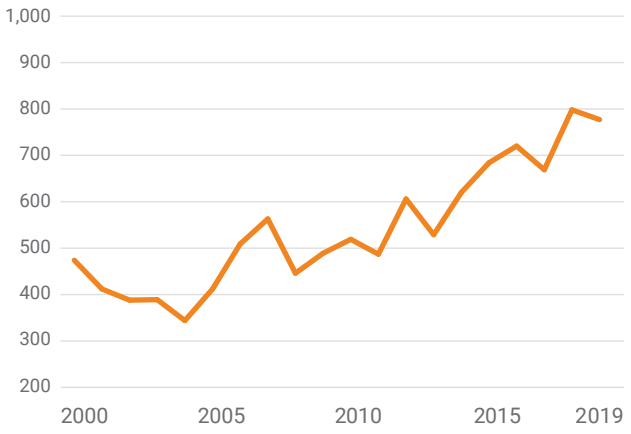
Unfortunately, we can take almost any one of these goals and show that we are not on track to achieve it. For example, the pace at which we are reducing undernutrition is not good enough to achieve the Sustainable Development Goal (SDG) for "zero hunger" (Figure B). And in terms of climate targets, our society has not taken the actions necessary to limit global warming to 2°C, let alone 1.5°C. With the current policies we may only achieve a disastrous 3.1°C to 3.7°C warmer world.[6] The number of climate-related natural disasters is climbing at an alarming rate (Figure C), with significant economic and health impacts, especially for the most vulnerable. Adaptation is needed on a large scale—there will be over 500 million small-scale agricultural producers in 2030—but we are not on target to build their resilience within a decade to greater frequencies and intensities of extreme events.

FIGURE B. Global prevalence of undernutrition



Source: data from FAOSTAT.[7]

FIGURE C. Number of extreme climate events worldwide



Source: Munich Re NatCatSERVICE.

Why this report?

Nothing short of a systemic transformation of food systems is required if we are to feed the world's current and future population sustainably under climate change.

Furthermore, as a significant driver of deforestation and contributor of greenhouse gases, the agriculture sector cannot be excluded from climate action if we are to meet global climate targets like the Paris Agreement.

We are not the first to argue that transformation is necessary. Others have demonstrated that it is needed to tackle a number of urgent issues —nutrition security, small-scale producer yields and incomes, poverty, gender disparities and social inclusion, biodiversity conservation and ecosystem protection, and shifting power dynamics, among others. But where, in the complexity of food systems, are the best levers to achieve change?

Through extensive research, analysis, and stakeholder consultation, we aimed to identify the **high priority actions that we must collectively take now, for climate change adaptation and mitigation in food systems**. Taken together, these actions are the basis of the systemic transformation that is needed in food systems.

We propose four action areas:

1. **Reroute farming and rural livelihoods to new trajectories**, to deal with greenhouse gas emissions, reduce inequality, address gender and social inclusion, and incentivize climate-resilient practices that meet dietary needs.
2. **de-Risk livelihoods, farms and value chains**, reducing the impact of variable weather and extreme events through attention to inclusive early warning systems, adaptive safety nets, and climate-informed advisories and other services.
3. **Reduce emissions from diets and value chains**, involving significant dietary shifts and massive reductions in food loss and waste.
4. **Realign policies, finance, support to social movements, and innovation** to build more resilient and sustainable food systems. This action area cuts across the other three, with attention to realigning subsidies and trade, dealing with power inequities and marginalization, bringing in billions of dollars in private sector investment, transforming innovation systems, and underpinning and supporting social movements addressing climate, livelihoods and food systems.

Within these four action areas are 11 transformative actions. For each action we identify a goal (the "what"), mechanisms to achieve this goal (the "how"), and target geographic areas (the "where").

As for the "who," everyone has a part to play in the transition. We outline roles for different stakeholder groups. As leaders of agencies and initiatives, we seek to mainstream relevant actions within our own organizations.

"If we are to achieve the global goals of a healthy planet, social equality, and economic opportunity, we need **solutions-oriented thinking that empowers stakeholders to take action.**"

—Juergen Voegele, Vice President for Sustainable Development, World Bank Group

Four Action Areas for Food Systems Transformation

1 Reroute farming and rural livelihoods to new trajectories

ACTION 1.1 **Ensure zero agricultural land expansion on high-carbon landscapes:** Avoid expansion on 250 million hectares of tropical forests and 400 million hectares of peatlands.

ACTION 1.2 **Enable markets and public sector actions to incentivize climate-resilient and low emission practices:** Bring 200 million farmers into appropriate markets by 2030 through increased profitability and market development.

ACTION 1.3 **Support prosperity through mobility and rural reinvigoration:** Build attractive rural livelihoods, including exits from agriculture, and create 20 million rural jobs by 2030, investing in infrastructure and youth.

2 de-Risk livelihoods, farms and value chains

ACTION 2.1 **Secure resilient livelihoods and value chains through early warning systems and adaptive safety nets:** End dependence on humanitarian assistance for 40 million rural dwellers by 2030, realigning US$5 billion per year for adaptive safety nets.

ACTION 2.2 **Help farmers make better choices:** Take climate services to scale by connecting 200 million farmers and agribusinesses to ICT-enabled bundled advisory services by 2030.

3 Reduce emissions from diets and value chains

ACTION 3.1 **Shift to healthy and sustainable climate-friendly diets:** Incentivize dramatic reductions in beef and dairy consumption in 15 high- and middle-income countries and all C40 cities by 2030.

ACTION 3.2 **Reduce food loss and waste:** By 2030, target 50% reductions in food loss and waste in five major supply chains where both greenhouse gasses and loss or waste are high.

4 Realign policies, finance, support to social movements, and innovation

ACTION 4.1 **Implement policy and institutional changes that enable transformation:** By 2025, realign US$300 billion of agricultural subsidies to a climate change agenda in 16 countries, improve “ease of doing business” in 24 sub-Saharan African countries, and significantly improve the readiness score of the ND-GAIN Index in 49 countries.

ACTION 4.2 **Unlock billions in sustainable finance:** Unlock US$320 billion in public and private capital per year to realize business opportunities in the implementation of the SDGs.

ACTION 4.3 **Drive social change for more sustainable decisions:** Reach 10 million young people by 2025 through science-based social movements to catalyze climate action in food systems.

ACTION 4.4 **Transform innovation systems to deliver impacts at scale:** By 2025, significantly change the approach of public agricultural research for development, with at least 50% of public investment in this research providing end-to-end solutions that support meeting the SDGs related to food.

CHAPTER 1

A food system report card

A "report card" for the global food system might look something like this: **Final grade** Grave concern

Quantity of food produced

On the face of it, the global food system has performed astonishingly well since the 1950s: real prices of food were constant (or even declining) until the early 2000s at the same time as the human population was expanding significantly, from about 2.7 billion people in 1955 to more than 7.7 billion today. Overall, there has been considerable and undeniable progress in reducing rates of undernutrition, from 37% in developing countries in 1969–71, to below 15% today and improving levels of nutrition and health. However, substantial regional differences exist. In addition, as a result of extreme events and unreliable weather, we have seen significant shortfalls in production in specific regions, which are likely to be exacerbated by climate change.[8]

Good—but regional challenges under climate change

Accessibility of food produced

The last three years have seen a rise in world hunger after a prolonged decline.[8] About one in nine people are undernourished, and 2 billion suffer micronutrient deficiencies. Undernutrition and severe food insecurity are increasing in almost all regions of Africa as well as in South America.

Previously improving—but now a cause for real concern

Human health and nutrition

Challenges remain around the "triple burden" of malnutrition: protein-energy malnutrition, micronutrient deficiency, and obesity. Global nutrition indices have been increasing since 2008 as decreasing deficits in nutrition have more than compensated for the rise in obesity globally.[9] This compensation may not last, however.

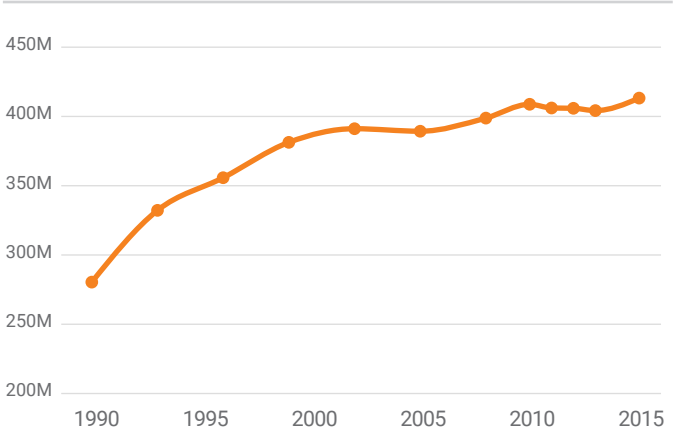
Good progress overall—but looming challenges

Rural poverty

Poverty rates are higher in rural areas than in urban ones (e.g., in 2013, 18.2% of rural residents and 5.5% of urban residents were in extreme poverty).[10] Thus despite decades of attention to agricultural development, poverty and food insecurity remain, especially among rural dwellers in South Asia, Africa and Central America.[11] In sub-Saharan Africa, numbers for extreme poverty are not coming down (Figure 1). Feminization of agriculture is occurring in many regions, partly as a result of male migration for employment.[12] Women's workloads are increasing, while the absence of the male household members reduces their access to services and resources.[13,14]

Regional challenges

FIGURE 1. Population living in extreme poverty in sub-Saharan Africa



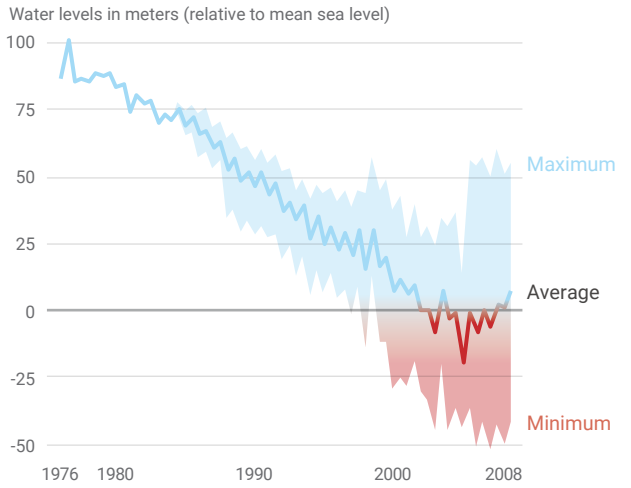
Source: data from Roser and Ortiz-Ospina, 2020.[15]

The environment

A major and increasing cause for concern

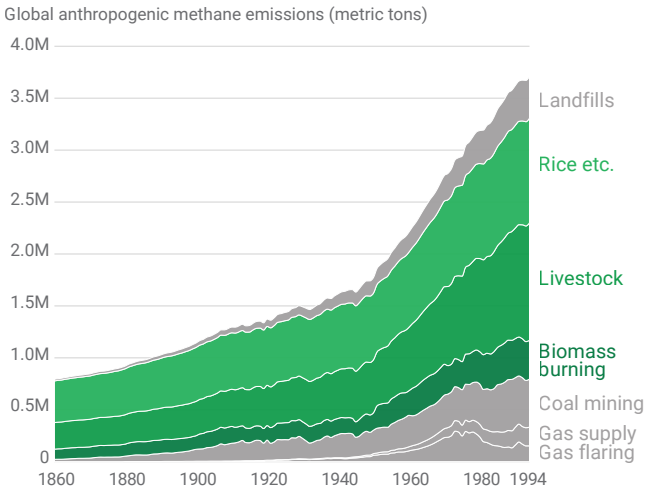
There has been huge expansion in food production in recent decades. On one hand, crop and livestock production have become considerably more efficient. For example, we now use 62% less land and emit 46% fewer greenhouse gasses (GHGs) to produce one kilocalorie from livestock, compared to 1961.[16] On the other hand, crop and livestock agriculture are playing a significant role in pushing the Earth system beyond safe operating boundaries with respect to biodiversity, and phosphorus and nitrogen use.[17] Increasing pressures from food production in other parts of the Earth system—GHG emissions, land system change and freshwater use—may also soon bump up against safe operating boundaries (Figure 2 and Figure 3).

FIGURE 2. Falling groundwater levels in Gujarat



Source: Columbia Water Center, 2019.[18]

FIGURE 3. Rising methane emissions, mostly from agricultural production



Source: Voiland, 2016.[19]

FINAL GRADE

Cause for grave concern

Recent decades have been characterized by rapid changes: increasing globalization; increasing inequality; the rise of consumer power and of social media; shifts in consumption; advances in technology; and rapid urbanization.

Then there is climate change. Increases in climate variability are already having effects on agricultural systems and these will intensify in the future—rising CO_2 concentrations are being linked to decreases in micronutrient densities of some staple crops[20]—and increasing frequencies of floods, droughts and extreme heat are already having serious repercussions for human wellbeing and health (Figure 4). These challenges are particularly problematic for many lower-income countries whose rural populations are largely reliant on agriculture and associated value chains. Many of these people are already food insecure and poor, and these are the people likely to be most affected by climate change.

As Bene and colleagues[1] write, "Our food system is failing us," while the EAT-Lancet report states that "global food production threatens climate stability and ecosystem resilience" (Figure 4). Can our food systems change rapidly enough? The window of opportunity for action is shrinking. Even a +1.5°C world will erode many of the advances that have been made in recent decades in food security and poverty reduction. The impacts on and disruptions to food systems, societies and economies of warmer trajectories require action. The pace of action to solve problems in the food system is worryingly slow. If we are to achieve the United Nations Sustainable Development Goals (SDGs) and the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement, we need to massively raise ambition.

> **"A radical transformation** of the global food system is urgently needed"
>
> *— EAT-Lancet report*

FIGURE 4. **Climate change and food systems by the numbers**

Climate change impacts on food systems

Climate change has already **reduced agricultural production by 1–5%** per decade compared to production levels expected with no climate change.[21]

On a +4°C emissions trajectory, **rainfed crop production** in most parts of southern Africa **will no longer be possible**. Common beans will no longer be viable.[22]

By 2050, **declines of 5–10% are projected in fish catch** in tropical marine ecosystems.[23]

By 2050, **175 million** more people will be **zinc deficient** and **122 million** more people will be **protein deficient** because of elevated CO_2 concentrations, mostly in Asia and Africa.[20]

Extreme events (droughts, floods and heatwaves) will become more frequent and intense. In 2018 alone, climate disasters directly affected nearly 30 million people and caused several thousand deaths.[24] Growing season climate factors—including mean climate as well as climate extremes—explain 20%–49% of the variance of yield anomalies, with 18%–43% of the explained variance attributable to climate extremes, depending on crop type.[25]

Up to **200 million people could be displaced** by climate change by 2050.[26]

A one standard deviation increase in drought intensity and length in Somalia **raises the likelihood of local violent conflict by 62%**.[27]

There is a strong link between drought and stunting in children. **Drought events in Bangladesh are associated with a higher stunting rate** around five to nine months after the onset of the event.[8]

Food system impacts on climate change

Between 2000 and 2010, **agriculture drove 80% of deforestation** worldwide.[28]

25–30% of total GHG emissions are attributable to the food system: 10–12% from crop and livestock activities on farms, 8–10% from land use and land use change, and 5–10% from the supply chain.[2]

Agriculture uses 86% of anthropogenic nitrogen. Half the nitrogen applied to soils is not taken up by plants.[29]

CHAPTER 2

Towards sustainable, inclusive, healthy and climate-resilient food systems by 2030

We envision a world in which all people, including future generations, are well nourished and food secure. This is a world achieved through food systems that can sustainably manage current and future stresses, both climatic and non-climatic. In this world, people are empowered to strengthen their resilience and adaptive capacity to climate-related hazards, while contributing to emission reductions and ensuring sustainable land use and the protection of ecosystems. This world is guided by the principles of leaving no one behind.

Various terms have been used to describe the kind of agriculture, or the approach to agriculture, that is needed to achieve this vision (Figure 5), but in this report we try to use these terms as little as possible, and instead focus on the outcomes to be achieved and the mechanisms for getting there.

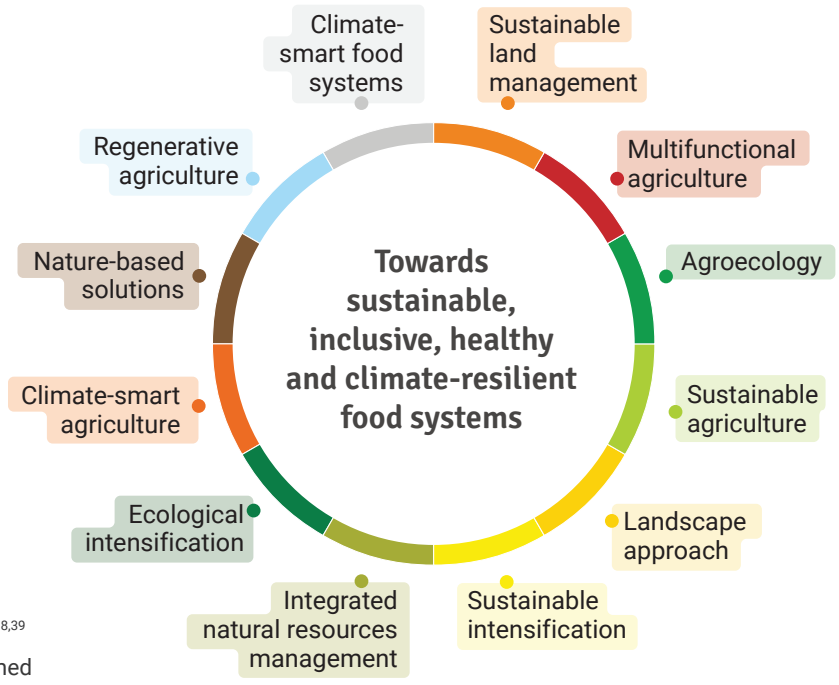
What is a food system?

The global food system[1] is a complex web of activities involving production, processing, transport, and consumption. A food system perspective includes governance and economics, ecological sustainability, and the impact of food on health.

Daunting targets must be achieved in food systems if the Paris Agreement targets and SDGs are to be realized. Food and nutritional security targets are themselves challenging, but they are now overlaid by the need to achieve zero net emissions globally, with substantial emission reductions and carbon capture in food systems.[2] In addition, global temperatures will overshoot 1.5°C, and are highly likely to overshoot 2°C, requiring more attention to adaptation and extreme events.

Transformational change that embraces food systems will be needed to realize this vision, as is recognized by numerous other initiatives and reports.[3,30,31,32,33,34,35] Transformation here refers to a significant and inclusive redistribution of inputs and outputs towards sustainable, inclusive, healthy and climate-resilient food systems.[36] It includes significant changes to the structure of landholdings, technologies and their use, capabilities and opportunities of women and men, and the distribution and dynamics of the population and labor force. Such a transformation will generate multiple benefits, including improved education, nutrition, health, water and sanitation, increased incomes for small-scale farmers, and empowerment of women and youth.[35,37,38,39] These benefits will translate to transformed and thriving livelihoods and communities.

FIGURE 5. **Terms used to describe approaches for transforming food systems**



Is transformation feasible? Examples of successful food system transformation in relation to climate change (or at least of components within food systems) are given in Box 1. While the number of cases is limited, the cases give us confidence that transformation is indeed possible.

While this report focuses on actions needed for transformation, including implementation of some near-ready technologies that may initially be highly disruptive to current food systems, we are cognizant that innovations that we are currently unaware of, or whose outcomes are currently uncertain, may indeed bring major transformations. These are the "wild futures," which we return to under Action 4.4: Transform innovation systems to deliver impacts at scale.

What is a transformation?

An agriculture and food systems transformation is a significant redistribution—by at least a third—of land, labor and capital, and/or outputs and outcomes (e.g. types and amounts of production and consumption of goods and services) within a timeframe of a decade.

Box 1. Examples of transformation

1. **Tigray, Ethiopia:** A region in which semi-arid conditions and high rainfall variability contributed to significant waves of famine. Drastic positive change—an increase in irrigated land area from 40 hectares to 40,000—was achieved through collective action and local leadership.[40]
2. **Langui, Peru:** Changes in climate and markets have reduced farmers' harvests. As a response, communities shifted from growing traditional staple crops to planting improved varieties of grasses for dairy production, opening access to a whole new dairy market.[41]
3. **Louisiana, USA:** Coastal erosion and sea level rise has reduced land area dramatically. Because of this, 400 out of the 600 members of the Native American tribe had to migrate, generating significant changes in labor activities. However, the affected communities took the initiative to lead their relocation and came together to exchange knowledge and organize advocacy through local and national social and political structures and systems.[42,43]
4. **Vietnam:** Dietary patterns in Vietnam have experienced dramatic changes during the last few years. This transition aligns with the national nutrition strategy, for which the 2012 goal was for 50% of Vietnamese households to achieve a dietary balance by 2015. By 2014, half of the population had a diet balance very close to the ideal.[44]
5. **Sweden:** Max Burgers has transformed its business model to be "climate positive" through 100% renewable energy in its stores, 92% renewable packaging, reduction of food waste to less than 1%, carbon footprinting of all items on its menu, 20% of all meals served being plant based, and 110% offsetting of all remaining value chain emissions.[45]

CHAPTER 3

Four action areas

Following a process involving extensive consultation with a wide range of stakeholders, a comprehensive literature review and commissioned background papers, we propose four action areas encompassing 11 transformative actions (Figure 6).[46]

The four action areas are:

1. **Reroute farming and rural livelihoods to new trajectories** that both reduce emissions and are climate-resilient;
2. **de-Risk livelihoods, farms and value chains** to deal with the increasing vagaries of weather and extreme events;
3. **Reduce emissions from diets and value chains**, targeting health and climate outcomes; and
4. **Realign policies, finance, support to social movements, and innovation** to facilitate action in the above action areas. This action area cuts across the other three, as policy, finance, innovation and social change are integral parts of those action areas.

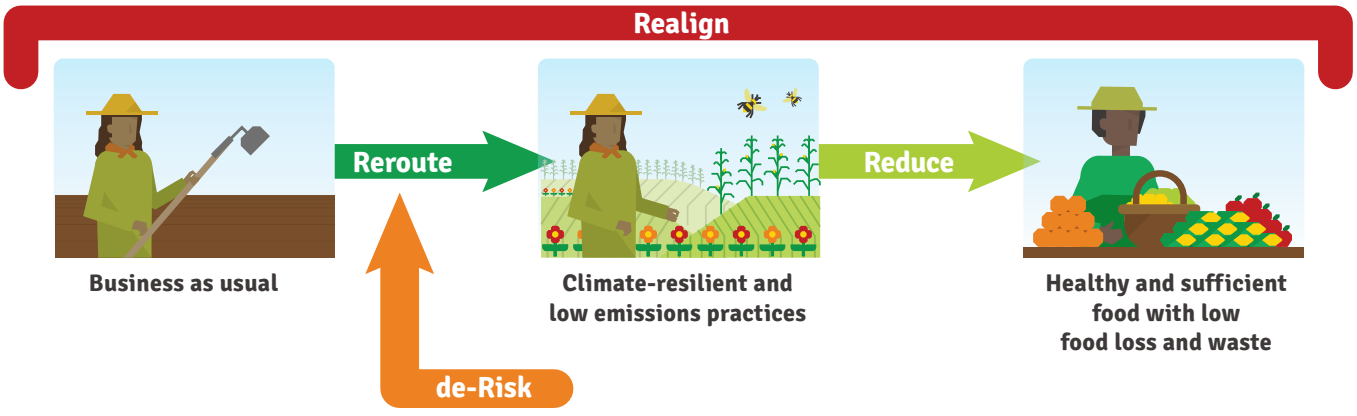
Rerouting actions target the most important sources of GHG emissions and stimulate climate-resilient sustainable practices, while also addressing inequality, gender, and social inclusion, and stimulating practices that meet dietary needs. The aim is to put farming and rural landscapes on new trajectories.

De-risking actions focus on securing resilient livelihoods and value chains through early warning systems and adaptive safety nets and helping farmers make better choices through the expansion of climate services based on greater connectivity, inclusivity, and public-private partnerships.

Reducing actions aim to decrease emissions by focusing on consumers and value chains by reshaping beef and dairy consumption in 15 high- and middle-income countries and all C40 cities, and reducing food loss and waste in major supply chains where both GHGs and food loss or waste are high.

Realigning actions focus on improving policies, finance, support to social movements, and innovation through shifting subsidies and trade to foster more resilient and nutritious food systems; unlocking the necessary finance to realize business opportunities for sustainability; underpinning social movements with science and support; and ensuring end-to-end solutions for actors in food systems.

FIGURE 6. **Interaction of the four action areas for food systems transformation**



While the focus of these actions is climate change adaptation and mitigation, all actions should have co-benefits that support other food system objectives (e.g., health benefits). That said, we recognize that each will have inherent trade-offs, and that implementation will be highly context-specific.

A clear example of a trade-off concerns nitrogen fertilizer (Figure 7). Too much fertilizer and there will be negative impacts on many SDGs. Too little fertilizer in specific contexts and the poverty and food security SDGs may be negatively impacted. In regions where soil fertility is extremely low and soil carbon is depleted—for example in the vast areas of mixed farming on granite sands in sub-Saharan Africa—additions of inorganic nitrogen will be crucial; on rich volcanic soils where coffee is grown, a completely different nitrogen strategy will be needed. SDG 12, ensuring sustainable consumption and production patterns, is central.[17]

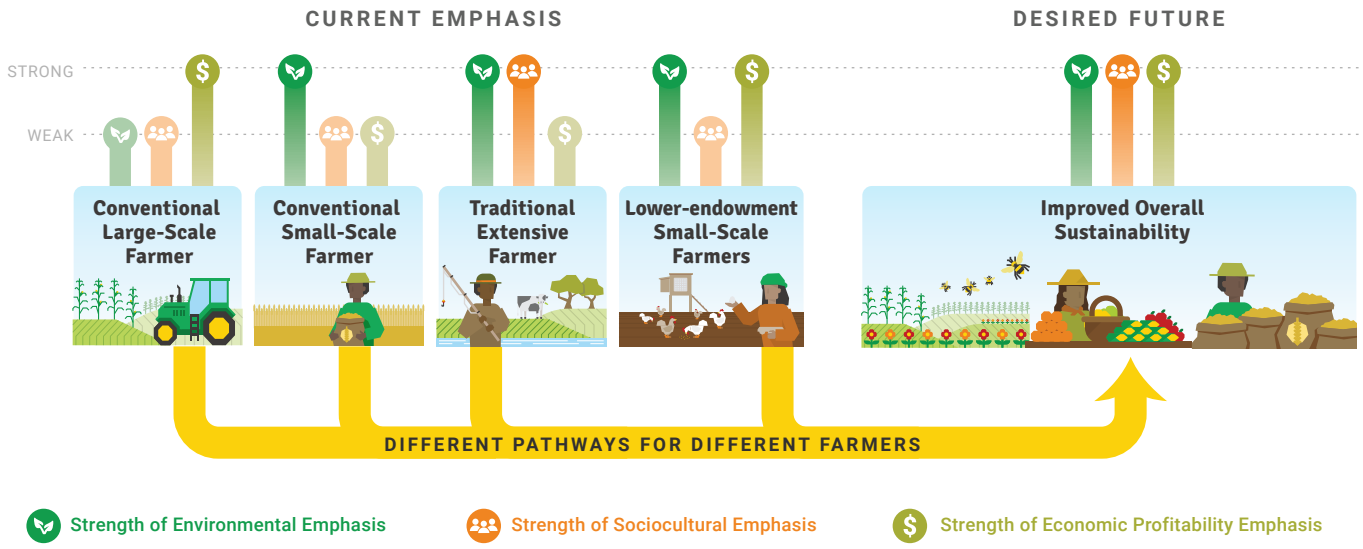
FIGURE 7. **Interactions among SDGs with respect to nitrogen (N) use**

Source: Campbell et al., 2018.[17]

Actions also have to be tailored to the diversity of farmer types and their specific assets. Many farmer types can be described; for example, Stringer and colleagues[47] highlight four (which we modify slightly): (i) conventional large-scale commercial farmers, (ii) conventional small-scale farmers, (iii) traditional extensive farmers further from markets in higher-risk environments (including many pastoralists and agro-pastoralists), and (iv) lower-endowment small-scale farmers (artisanal and low-input, some rural and some peri-urban, a small proportion of whom will be supplying niche products to diverse urban consumers). As Figure 8 shows, actions required to achieve sustainability need to have different emphases for each of these farmer types to move to sustainable systems, considering environmental, sociocultural and profitability goals.

To generalize at a high level, and also recognizing that for many farms it is not a single pathway that will be adopted: For conventional large-scale commercial farmers (about 70 million farms), pathways will need to focus particularly on improving environmental outcomes. For conventional small-scale farmers (up to approximately 320 million), pathways will need to focus on increasing market integration—with perhaps half of these able to harness the digital world, in the short term, for better

FIGURE 8. **Different pathways for different types of farmers**



decisions. This group is often referred to as farmers that are "stepping up."[11] For the more extensive farmers in environments that face considerable climate hazards (about 30 million), pathways will be needed to build assets and safety nets to increase their resilience and productivity. These are farmers that are "hanging in," but hopefully transitioning to "stepping up." And for lower-endowment small-scale farmers (about 150 million), pathways will be needed that revitalize rural economies as well as foster meaningful transitions to urban economies (safety nets are also important for this group). This group includes those "hanging in" and food insecure, with the ambition of getting many to "step out." Highly indicative numbers of farmers in the different groups are shown in Table 1.

TABLE 1. **Highly indicative number of types of farmers by region (millions)**[48]

REGION	LARGE-SCALE COMMERCIAL FARMERS	CONVENTIONAL SMALL-SCALE FARMERS		MORE EXTENSIVE FARMERS IN RISKIER ENVIRONMENTS	LOWER-ENDOWMENT SMALL-SCALE FARMERS	TOTAL
		LESS LIKELY TO BE DIGITALLY CONNECTED	MORE LIKELY TO BE DIGITALLY CONNECTED			
Central America	2	2	3	<1	<1	**9**
East Asia & Pacific	15	87	106	<1	<1	**208**
Europe	28	7	7	0	1	**43**
North America	2	<1	<1	0	0	**2**
South Asia	2	13	41	9	105	**169**
South America	9	2	1	<1	<1	**12**
Southeast Asia	4	32	4	3	12	**55**
Sub-Saharan Africa	3	9	<1	16	26	**54**
Middle East and North Africa	5	<1	8	2	8	**24**
TOTAL	**70**	**154**	**169**	**31**	**154**	**577**

ACTION AREA 1

REROUTE farming and rural livelihoods to new trajectories

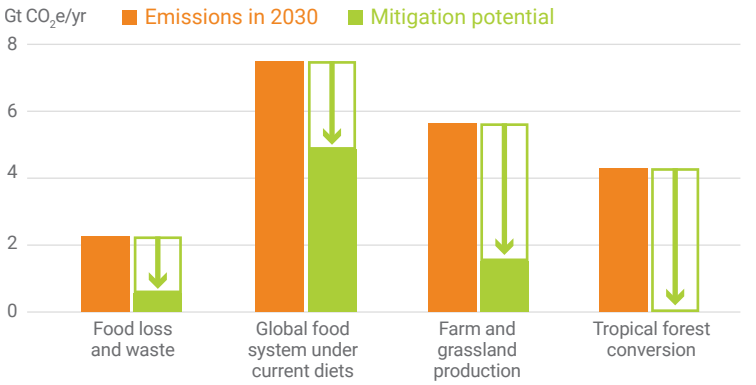
Climate change mitigation

The Paris Agreement sets a clear target for climate change mitigation: to hold the global increase in temperature to well below 2°C and pursue 1.5°C above pre-industrial levels. As a sector, agriculture cannot be excluded if we are to meet these goals.[49,50,51] Agriculture drives most deforestation and contributes 10–12% of global GHGs annually. But mitigation in agriculture is constrained by weak incentives and limited access to improved technical options. Only about 20–25% of projected emissions in 2030 can be reduced using current best practices, but up to four times more mitigation could be achieved with more structural changes, such as dietary shifts away from ruminants, more efficient supply chains or relocating production to more efficient locations.[52] Based on the mitigation technically possible, priorities for reducing emissions in food systems are:

- Preventing agricultural land expansion in high-carbon landscapes (Action 1.1);
- Changing diets, with a focus on animal-sourced food (see Reduce: Action 3.1)
- Reducing food loss and waste (see Reduce: Action 3.2)
- Research on possible breakthrough technologies to reduce emissions (see Realign: part of Action 4.4).

Figure 9 shows the relative importance of emissions sources in food systems and their associated mitigation opportunities.

FIGURE 9. **Climate change mitigation opportunities in the food system in 2030**



Data sources: Pendrill et al. 2019,[53] Searchinger et al. 2019,[54] Vermeulen et al. 2012,[55] Gibbs and Salmon 2015,[56] EAT-Lancet Commission 2019,[3] Smith et al. 2007,[57] Springmann et al. 2018[58].

In 2030, agriculture-driven land-use change will continue to provide the most significant opportunity for land-based mitigation, ~4.3 Gt CO_2/yr. This estimate is based on past expansion of croplands, pastures and forest plantations (2.6 Gt CO_2/yr)[53] and projections of 2050 emissions due to agriculture-driven land-use change (6 Gt CO_2/yr)[54]. An additional land area of ~593 million ha—about half the size of China, the US or Canada—is expected to be needed to meet 2050 food demand.[54]

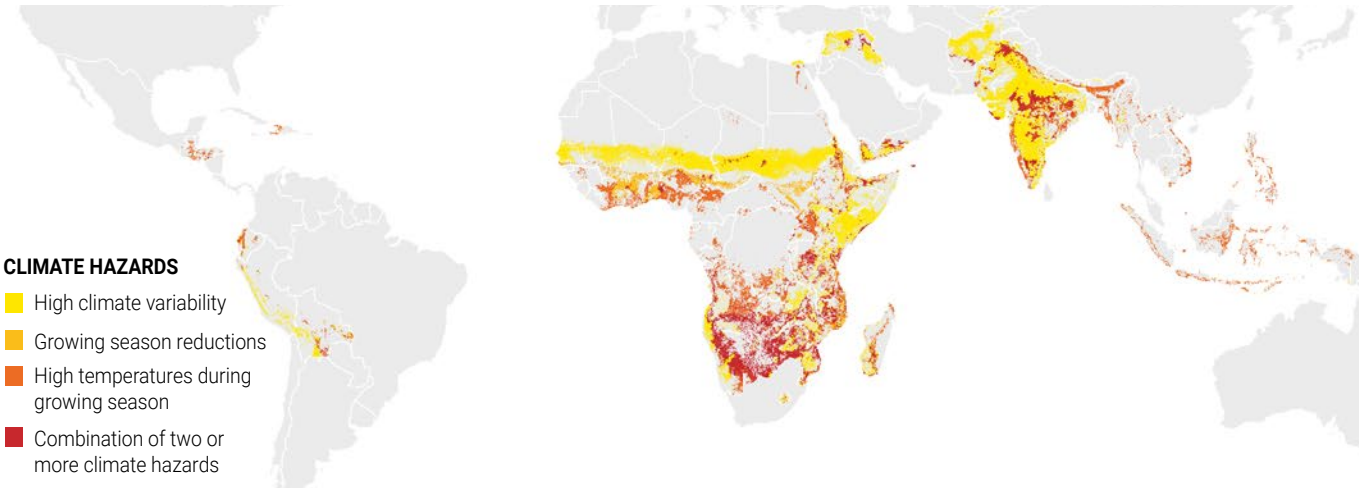
ACTION 1.1

Ensure zero agricultural land expansion on high-carbon landscapes

Climate change adaptation

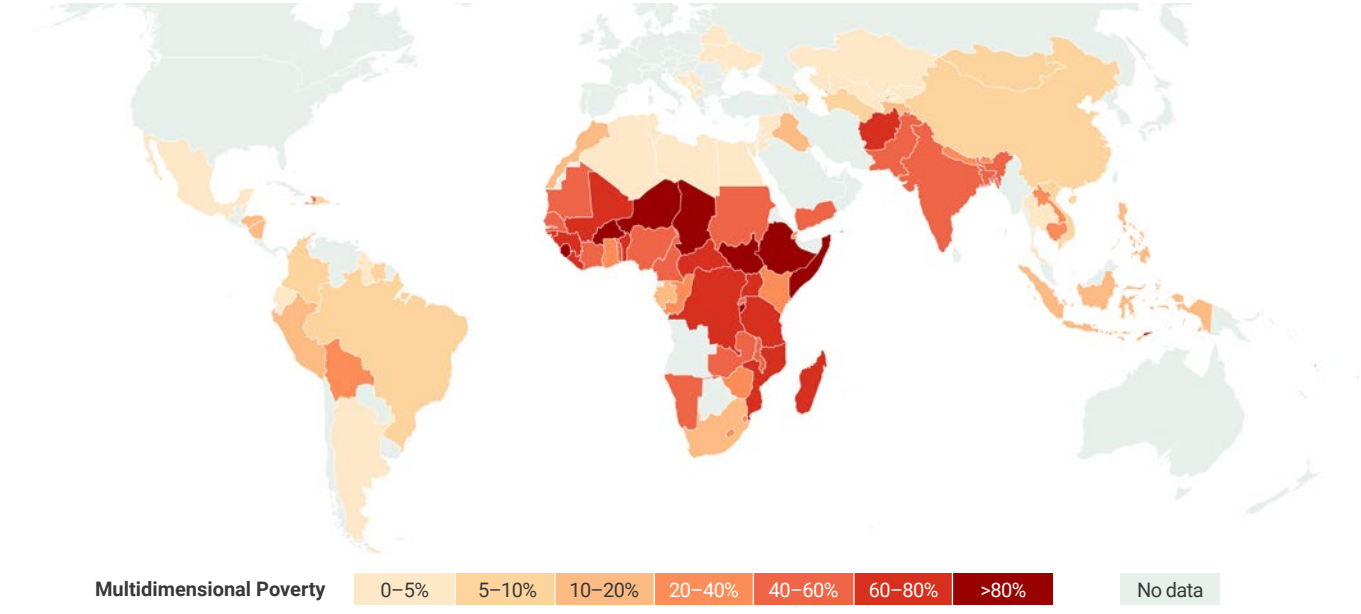
The priority for climate change adaptation is to reduce vulnerability to increasingly variable weather and extreme events while not losing sight of long-term adaptation challenges.[59] Because vulnerability to climate change is so closely linked to poverty, hotspots for poverty are generally also hotspots for climate action (Figure 10).

FIGURE 10A. **Areas of extreme climate vulnerability**[60]



Source: Thornton et al., 2019.[11]

FIGURE 10B. **Percentage of population in multi-dimensional poverty in three global regions**[61]



Source: Roser and Ortiz-Ospina 2020.[15]

In many climate change and poverty hotspots, there are significant differences between potential agricultural productivity and actual agricultural productivity—the so-called yield gap.[62,63] It is essential to close these yield gaps to deliver food security, while avoiding dangerous cropland expansion and resultant negative environmental impacts, including climate change. There are many known technologies and practices that could reduce yield gaps, which are also climate-resilient and can have lower emissions (e.g., drought-adapted maize varieties, conservation agriculture technologies, micro-dosing of fertilizer). Yet, reaching scale through adoption of improved technologies has proven challenging over the past decade. Thus for this action we focus more on the markets and institutions to drive scaling than on the technologies. Actions to reduce risks and enhance market opportunities for small-scale agricultural producers can foster technology uptake and radically change livelihood opportunities.[64] Improved water management and improved varieties and breeds show particular promise for building climate resilience.

ACTION 1.2

Enable markets and public sector actions to incentivize climate-resilient and low emission practices

Building rural livelihoods and transitioning out of farming

Adaptation in rural areas is doomed to failure without a renewed commitment to rural life. With youth populations exploding and significant out migration from rural areas (within and between countries), there is a sense of doom and gloom around agriculture-centered livelihoods, which bodes poorly for the effectiveness of any climate adaptation strategy[65]. A reinvigorated rural economy is needed to spur agriculture to shift from being a direct (often subsistence) employer to a driver of rural development and growth. Agriculture must become attractive to the next generation as a sector with opportunities, not only in farming per se, but also in a rural service economy. It must also be inclusive, of both women left behind farming[66,67] and next generation youth who are increasingly disenfranchised in rural areas. As climate bites harder during the 21st century, policies must also recognize when economic transformation of regions is needed, and must facilitate communities to effectively transition out of agriculture where necessary. Such facilitated and planned transitions will reduce suffering and economic hardship.[68] Exiting agriculture and pursuing alternative livelihoods should be a valid pathway for some rural dwellers.

ACTION 1.3

Support prosperity through mobility and rural reinvigoration

> "**Climate change threatens the food systems that billions depend on**—it is a huge challenge that needs huge solutions. This is why we must join forces and reform markets, agricultural practices, and livelihoods. Only then can we successfully mitigate the effects of climate change and stop the destruction of our ecosystems."
>
> *—Dr Grethel Aguilar, Acting Director General, International Union for Conservation of Nature (IUCN)*

ACTION 1.1

Ensure zero agricultural land expansion on high-carbon landscapes

CHALLENGE 1.1: Avoid expansion on 250 million hectares of tropical forests and 400 million hectares of peatlands

WHAT: The outcome envisaged is sustainable agricultural productivity sufficient to meet global food needs up to 2050, without requiring further conversion of high-carbon forests, peatlands and grasslands. Policies effectively regulate market demand, and location and expansion of commodity crops and livestock production ensure food security while avoiding loss of high-carbon landscapes.

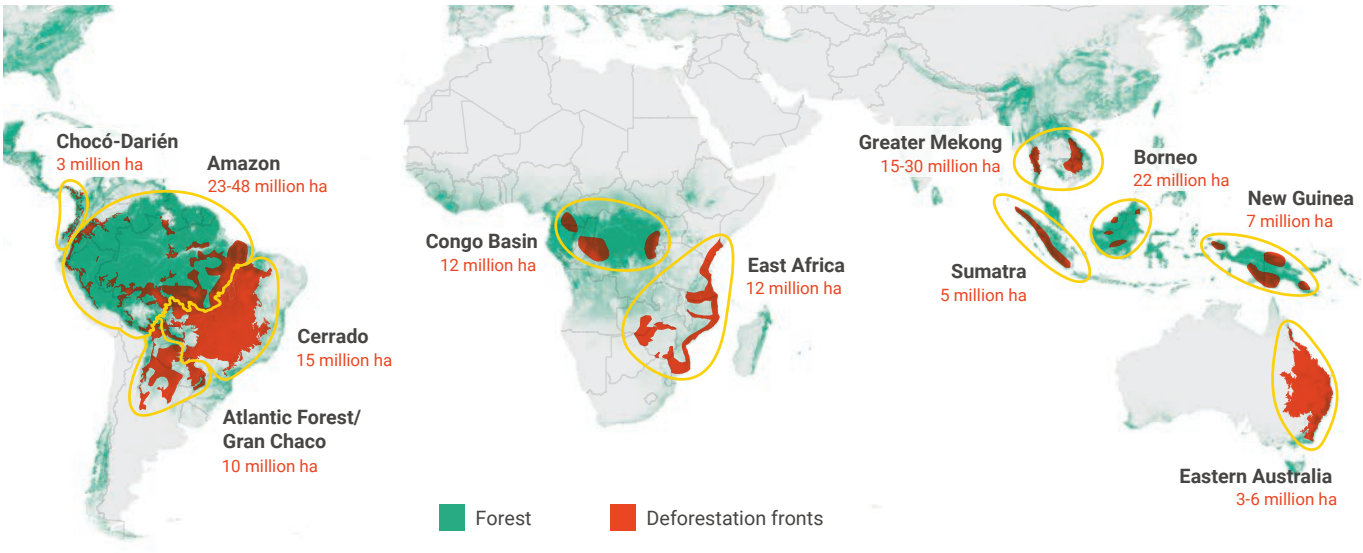
WHY: Most agricultural expansion in carbon-rich landscapes is driven by only a few market commodities.[69] Multiple initiatives already exist to hold investors and purchasers of these commodities accountable to zero deforestation, regulate land use, and reduce pressures for land-use change.[69] Building on these efforts to more comprehensively include all high-carbon landscapes (e.g., peatlands, grasslands and soils with high soil organic carbon) will enable more rapid and ambitious mitigation to be achieved.

HOW: Mechanisms to achieve the outcome include:

- **Improving transparency and accountability of finance and major commodity supply chains driving conversion of high-carbon landscapes** (Box 2). Developing more ambitious industry and finance standards, green banks, company policies for zero agricultural land expansion, disclosure requirements, subsidy reform, and robust verification methods. Focus: palm oil, beef, soy, pulp, rubber, cocoa and coffee.
- **Transforming procurement and supply chain policies** for key commodity crops to require purchase of products outside specified geographic "no-go zones" such as the 11 deforestation fronts (Figure 11), based on information campaigns aimed at consumers and product traceability. Includes all peatland, grasslands and high-carbon soils.
- **Using national policy regulation and enforcement, together with real-time remote sensing, to secure and enforce protection of high-carbon landscapes.** Protected areas and land-use plans should be expanded to consider all high-carbon lands. Enforcement of boundaries should be incentivized with climate finance, penalties for transgressors, and use of independent judicial bodies and watchdog organizations. Automated real-time digital monitoring of land use in protected areas should make information widely accessible. Protection of high-carbon lands should be a cornerstone of the Nationally Determined Contributions (NDCs).
- **Organizing consumer advocacy and using media** to build awareness of the impacts of purchasing decisions. Linking networks of NGOs concerned with deforestation, climate and food systems to support consumer education and advocacy, media campaigns and boycotts.
- **Intensification and relocation of commodity agriculture**, to decouple agricultural production from land area requirements and encourage locations far from land conversion fronts (Box 3). Sustainable intensification of agriculture could be a cornerstone of NDCs.

WHERE: The majority (80%) of global forest loss by 2030 is expected to take place in 11 deforestation fronts, nearly all of which are in the tropics (Figure 11). South America will have the largest losses. Additional high-carbon lands (peatlands, grasslands, and other high-carbon soils) should be similarly mapped and designated as "no-go" zones.

FIGURE 11. **The 11 deforestation fronts, with projected losses, 2010–2030**



Source: WWF, 2015.[70]

SDGS SUPPORTED:

BOX 2. **Integrating policy, markets and farm-level action to stop deforestation in Brazil**

Cattle ranching and agriculture, including fire for clearing land, are major drivers of forest loss in the Amazon. Recent government policy in Brazil has loosened forest protection policies, leading to the highest levels of deforestation in a decade. The Zero Deforestation Working Group—a coalition of Greenpeace Brazil, Instituto Centro de Vida, Imaflora, Imazon, Amazon Environmental Research Institute (IPAM), Instituto Socioambiental, WWF Brazil and The Nature Conservancy (TNC) Brazil—has identified a four-part plan to stop deforestation in the region. The four parts are: 1) implement environmental public policy; 2) support sustainable forest use and best farming practices; 3) restrict markets for products driving new deforestation; and 4) engage Brazilian voters, global consumers and national and international investors.[71] TNC, for example, has been working with Cargill to help 158 soy farmers register their farms to support responsible beef sourcing. TNC and partners have also been supporting municipal governance for sustainable beef to improve environmental monitoring for implementation of Brazil's Forest Code.

BOX 3. Land-use fiscal policy in Indonesia to drive diversified land use

The Indonesian government and the Climate Policy Institute (CPI) have collaborated on developing fiscal policy at national and local levels to better balance economic and climate objectives, including in areas where oil palm expansion has been a major driver of deforestation.[72] This has included regulation to establish an environment fund managed via a public services agency and the 2018 launch of the SDG Indonesia One Fund to provide blended finance instruments for projects that contribute to the SDGs. The fund attracted investment commitments of up to US$2.3 billion on the day of its launch. At the local level, CPI found that using village funds for more diversified economic activities, rather than on a single sector such as oil palm, can support more sustainable land use, and that palm oil production can be optimized with minimal land expansion.

ACTION 1.2

Enable markets and public sector actions to incentivize climate-resilient and low emission practices

CHALLENGE 1.2: Bring 200 million farmers[73] into appropriate markets by 2030 through increased profitability and market development

WHAT: The outcome envisaged is climate-resilient technologies widely adopted (including micro-irrigation based on novel business models, climate-resilient seeds and breeds, diversified production, etc.) and farmers more integrated into markets, enhancing their income and resilience.

WHY: Persistent yield gaps, poverty and climate vulnerability are apparent in much of sub-Saharan Africa, South Asia and Central America. There are many well-known climate-resilient practices that would improve productivity, but adoption is low. Market-based approaches can provide incentives to adopt, if producers see the benefits to their livelihoods. With continuing rapid urbanization, there are opportunities to engage new markets. In northern Tanzania, for example, some of the most significant changes made by farmers relate not to any specific agricultural intervention but more to expanded rural-urban market linkages.[74] This suggests that farmers in rural areas with good market opportunities can be agile.

The high risks to production and marketing, including climate risks, need to be overcome (see Action area 2: de-Risk). There will also be winners and losers in market-based approaches; those unable to engage markets need to be targeted for livelihood security (see for example, Actions 1.3 and 2.1). Advancing gender equality and youth opportunities is a priority, given the very high rates of unemployment among young people, women's prominence among people living in poverty, their lack of access to resources and power, and the disproportionate agricultural labor burden that women face.[11,75]

HOW: Mechanisms to achieve the outcome include:

- **Incentivizing private sector investment in expanding and diversifying markets**. Reforming regulatory frameworks to greatly enhance "ease of doing business," putting in place incentives for new processing industries that help informal actors and small-scale entrepreneurs grow and diversify, and putting in place policies that facilitate private sector investments in expanding and diversifying markets. Installing processing and cold chain facilities that underpin future resilience to climate change, and that contribute to rural employment. For example, in Ethiopia, a public-led process is leading to major changes in production (Box 4).
- **Expanding access to credit.** Many millions of rural small-scale producers and value chain actors are unable to access the loans, insurance and credit they need, in part because banks and other financial intermediaries consider the risks as too high.[76] By developing and implementing innovative approaches such as value chain lending, mobile-based finance (Box 5) and other approaches that move beyond private collateral as the basis for lending, credit access can be expanded.

- **Expanding sustainable micro-irrigation** based on renewable energy sources in areas of high rainfall variability. High costs can prevent this expansion. By using fintech, public-private partnerships and solar-powered micro-irrigation schemes, irrigation can expand at lower cost to farmers.
- **Diversified and dynamized seed systems.** Access to good quality climate-resilient seed is a serious constraint for many small-scale farmers. Access can be enhanced by targeting technology deployment aligned with seasonal climate outlooks and site-specific conditions, by developing protocols for collaboration between national genebanks and community seedbanks, and by establishing policy dialogues around streamlining national seed policies and multi-country seed sharing agreements to increase resilience.
- **Doubling down on technology dissemination strategies.** Farmers often have limited access to information about new technology and what it means for them. Access to improved varieties and breeds and other climate-resilient technologies can be enhanced through extension services and digital advisories (using for example, mobile phones, radio, and TV), coupled with financial incentives to reduce upfront costs.
- **Empowering farmers, women and youth, and their organizations.** Farmers, women and youth are often marginalized in development programs. If food systems transformation is to succeed, farmers must have a central role. Strengthening farmer, women's and other local organizations, and their networking, is key to transformation. At the same time, actions are needed to create enabling environments that encourage producers, business owners, researchers, investors and policy makers to innovate in ways that promote gender equality, youth empowerment and entrepreneurship. Constraints can be addressed by increasing access to financial resources,[77] making available technologies that suit women's preferences and tasks and don't increase their workload,[78,79,80,81] supporting women's access to markets, and supporting their decision-making power in choice and use of technologies[75,82].
- **Developing and testing innovative models for access to and ownership of land by women and marginalized farmers** in the context of restricted land rights for women and increasing agri-investment by the private sector. Collaborative models, such as outgrower schemes and other collective arrangements, may be alternative approaches. Reforms to systems of land tenure can greatly incentivize farmers to sustainably intensify their production through improved access to credit to purchase inputs.

WHERE: Climate change and poverty hotspots in sub-Saharan Africa, Latin America and Asia.

SDGS SUPPORTED:

BOX 4. Ethiopian Agricultural Transformation Agency (ATA)[83]

The Ethiopian Agricultural Transformation Agency (ATA) was established in 2010 to catalyze transformation in the smallholder agriculture sector from low input-low output, subsistence-oriented production to a more market-orientated approach. ATA addresses systemic bottlenecks that hinder sectoral change. The transformation agenda is being strongly driven by robust evidence and novel analytics, widespread capacity development, and policy analysis to manage change that will transform the agricultural sector and bring impact at scale. As an example, over one million hectares of degraded land have been restored in Tigray and the area irrigated has increased massively, enabling farmers to produce higher-value vegetables and fruits even in drought years.

BOX 5. Mobile money empowers women in Kenya[84,85]

Mobile money has supported 194,000 households in Kenya, lifting them out of poverty. The majority were female-headed households. M-PESA influenced changes in financial behavior, especially increased financial resilience and saving, with many moving out of agriculture and into small business as a result. Mobile money is also a platform that gives women control over their finances.

ACTION 1.3

Support prosperity through mobility and rural reinvigoration

CHALLENGE 1.3: Build attractive rural livelihoods, including exits from agriculture, and create 20 million rural jobs by 2030, investing in infrastructure and youth[86,87]

WHAT: The outcome envisaged is communities living on the front line of climate change where their livelihoods become unsustainable are facilitated to transition into alternative livelihood strategies, either through assisted migration or purposeful economic diversification programs. In medium- and high- potential agricultural areas, jobs are created in and around agriculture, providing services, targeting youth particularly, enhancing happiness indices, building more resilient and diversified livelihood strategies, and generating economic prosperity more broadly at national level.

WHY: Common trends in rural areas include: diversification of rural livelihoods, increased agricultural and non-agricultural wage labor, and temporary and permanent migration to new livelihood options.[88] The challenge is to create attractive rural livelihoods, in or out of agriculture, and to build skill levels and opportunities so that exiting agriculture is a viable and better option. Rural reinvigoration in some places may involve the development of new industries and with them the creation of new jobs. In others, integrated landscape approaches that increase productivity, enhance resilience and maximize the value of ecosystem services may be appropriate. Migration, and the remittances that result from it, can help improve livelihoods, for both migrants and the relatives who remain behind (Box 6).

HOW: Mechanisms to achieve the outcome include:

- **Investing in rural infrastructure**, hard and soft. Rural infrastructure is not a high priority for many governments. This can be changed by developing robust cost-benefit analyses co-created with policy makers that clearly demonstrate the value of improved road networks, accessible public transportation, and better access to rural areas; the societal benefits of improved urban-rural linkages that facilitate access to rapidly expanding and dynamic urban markets; and the role that improved education and health systems and reformed land tenure systems can play.
- **Investing in secondary and tertiary industries in rural areas.** Few employment opportunities exist outside of agriculture in many remote rural areas. This can change if policy makers at national and local levels co-develop shared, normative visions of the future, and identify the policies that will be needed to develop appropriate secondary and tertiary industries in rural areas in order to diversify rural economies beyond a reliance on agriculture alone.
- **Revolutionizing agricultural production systems towards greater automation** (Box 7). A combination of lack of knowledge and a dearth of opportunities for farmers and cooperatives to access the start-up capital required stops greater automation. This can be overcome by putting in place a set of pilot demonstrations revolving around reducing drudgery and utilizing innovative financing mechanisms (such as value chain lending, see 1.2 above).

- **Capacitating youth** for rural entrepreneurship. Many young people view agriculture as uneconomic and unrewarding work. This can be changed by incentivizing investments in training and re-skilling of the workforce so that producers and rural dwellers can engage in new activities such as agro-processing, distribution and provision of farm inputs, and being infomediaries through ICTs. Steps will need to be taken to ensure that young women can also take advantage of these opportunities.[89,90]
- **Establishing safety net policies to facilitate migration out of failing farming systems.** Creating programs that facilitate migration of households either to more prosperous regions when farming becomes unviable or promote mobility to other parts of the food system beyond the farm gate. National planning processes could be much more ambitious with respect to safety net policies and programs as a highly cost-effective adaptation measure.

WHERE: Climate change and poverty hotspots in rural sub-Saharan Africa.

SDGS SUPPORTED:

BOX 6. Adapting through migration in the Mekong Delta, Vietnam[11,91]

Over the past 20 to 30 years, rainfall patterns in the upper delta of the Mekong River have changed. The area is flooded annually, which enriches the soil but is also a threat to communities in the area when floods are higher than usual. Nevertheless, and despite an increase in rainfall, flood levels have decreased over the past 20 to 30 years given water retention upstream, with negative impacts on rice yields. Out-migration has increased, particularly in the past 10 years. Most migrants leaving for long periods have moved to industrial zones outside the Mekong Delta. Migrant remittances have been used to buy food, pay back loans and implement in situ adaptation activities such as diversifying into non-farm activities, saving money through community-based saving schemes, raising the foundations of houses, and investing in children's education to enable them to get good jobs outside agriculture. This case highlights the importance of remittances as a means of improving livelihoods.

BOX 7. Hello Tractor: reducing drudgery in African agriculture[92,93]

Hello Tractor is a US- and Nigeria-based agtech social enterprise that connects tractor owners with farmers in need of tractor services. Many smallholder farmers lack the capital to purchase machinery, but through Hello Tractor they can rent a tractor at a fraction of the cost and thus reduce drudgery in their farm labor. The enterprise is now providing services to thousands of farmers in sub-Saharan Africa, facilitating mechanization and increased productivity for those who access the service, as well as generating new employment opportunities for digital entrepreneurs in rural areas. For example, Hello Tractor has trained 250 young and digital technology-savvy "booking agents" in Nigeria to help identify and aggregate demand, and link up with tractor suppliers to help ensure the tractor fleet linked to the network is kept busy and productive throughout the year.

ACTION AREA 2

DE-RISK livelihoods, farms and value chains

Climate-related risk is an obstacle to efforts to improve food security and farmer livelihoods. Extreme events, such as droughts, flooding, shifts in the seasons, and heat waves, can trigger food crises and erode farmers' capacity to build a better life by depleting their productive assets and human capital. The uncertainty associated with climate variability is a major obstacle to adoption of agricultural innovations and investment in value chains. De-risking agriculture requires action both (i) to protect development gains, farmer livelihoods and food security from the impacts of increasingly severe extreme events; and (ii) to promote farmer livelihoods by overcoming risk as a barrier to adoption of innovations, access to credit and development of value chains. Appropriate use of climate information and development of climate services are foundational for both actions. For the millions of smallholder farmers who are "hanging in," an unanticipated and unmitigated climate-driven shock can erode assets and impair the long-term health and productivity of children, thereby reducing prospects for escaping poverty. For the millions "stepping up," climate risk can hinder further investment.

Innovative systems for early action, supported by early warning systems and well-designed triggers, reduce the costs and improve the timeliness and effectiveness of humanitarian intervention. Safety nets, in the form of government social protection programs that provide cash transfers and other services, are an increasing part of the efforts of low-income countries to protect the wellbeing of poor and vulnerable groups. By securing poor households' access to adequate nutrition and health care, they play a particularly critical role in the health of women and children. These solutions are also about shifting humanitarian aid to focus on prevention and resilience-building strategies, and about safety nets to protect the millions of smallholder farmers who are "hanging in" from potentially devastating impacts of increasingly frequent and intense extreme climate events.

ACTION 2.1

Secure resilient livelihoods and value chains through early warning systems and adaptive safety nets

Although climate impacts on smallholder farmers are most visible when major food crises occur, unanticipated climate risk has a greater although less visible impact as an obstacle to farmer investments. The negative impact of climate risk extends to value chain actors and rural financial services, whose subsequent decisions can constrain farmers' efforts to build a better life.

In order to manage climate-related risks, those risks must first be understood, anticipated and factored into decision-making. Effective climate services, integrated with agricultural advisory services, enable farmers to adapt their farming and livelihood practices to their local climate, protect their lives and livelihoods when adverse conditions are anticipated, and invest in more profitable practices when more favorable climatic conditions are anticipated. Innovations in index-based agricultural insurance have largely overcome the obstacles to insuring smallholder farmers. By reducing risk as a barrier, well-designed and targeted insurance catalyzes adoption of more profitable production technologies and practices, and access to credit. Bundling complementary services—such as climate information, technical advisories, pest and disease early warning, insurance, credit, input supply, and market information—exploits synergies and creates economies of scale that reduce costs and accelerate uptake.

"If African farmers are to prosper in the face of climate change, we need to de-risk their efforts to innovate. Provision of ICT-enabled advisory, insurance and other services, as well as digitization, is key to de-risking livelihoods, farming enterprises and value chains."

– Ishmael Sunga, CEO, SACAU

The impact of these de-risking actions on farmers' livelihoods is constrained in part by limited capacity in low- and middle-income countries to tailor and deliver them to large, remote, heterogeneous rural populations. National agricultural extension services and national meteorological services play a crucial role in the generation of quality information. However, these services have been perennially underfunded and have failed to deliver their full potential in most low- and middle-income countries. Rapidly expanding mobile phone penetration in rural areas, combined with agricultural extension services (where they are effective) and broadcast media, is opening new opportunities for the development and delivery of services to farmers, at scale (Box 8).

ACTION 2.2

Help farmers make better choices

BOX 8. Esoko: delivering climate information through a public-private partnership in Ghana

In Ghana, a public-private partnership business model adopted by Esoko has encouraged mass subscription to climate information services through mobile phones. The partnership targets farmers subscribing to the Planting for Food and Jobs initiative introduced by the Government of Ghana as part of its measures to improve food security and employment in the agricultural sector. The partnership includes private telecommunication companies and public institutions. To foster more subscriptions, Esoko and Vodafone developed the Vodafone Farmers Club, a network of farmers benefiting from market information and climate information delivery services. Current member farmers pay 20 cents (US$) per month to receive timely market alerts and climate information on their mobile phones. These payments are made as direct debits as farmers recharge their phones with Vodafone scratch cards. Multiple benefits, including free airtime to call members of the group, has increased interest in the subscription. An impact assessment indicates that more than 300,000 farmers are now being served. This kind of approach has potential to reach women widely, but further work is needed on addressing gender barriers.[94,95]

ACTION 2.1

Secure resilient livelihoods and value chains through early warning systems and adaptive safety nets

CHALLENGE 2.1: End dependence on humanitarian assistance for 40 million rural dwellers by 2030, realigning US$5 billion per year for adaptive safety nets[96]

WHAT: The outcome envisaged is preventative measures are put in place that reduce the frequency and magnitude of climate-induced crises in regions with significant climate risk. In these places, safety net policies and programs provide for resilient livelihoods during and after extreme climate events, reducing human suffering, enhancing food security and sustaining and enhancing development gains.

WHY: In 2019 (up to November), donors provided US$16 billion for inter-agency appeals. This figure rises to US$21 billion when funding from outside the appeals is included.[97] This meets only a portion of the need projected by the UN Office for the Coordination of Humanitarian Affairs, estimated at US$29.7 billion for 166.5 million people. Many of these situations are viewed as complex, with the top eight worst food crises linked to both conflict and climate shocks.[97] In 2019, according to the FAO, of the 113 million people in the world suffering acute hunger, 74 million suffer due to conflict and insecurity, 10.2 million due to economic shocks, and 29 million due to natural disasters.[98] A joint UNICEF-WFP report on the return on investment (ROI) for emergency preparedness (the pre-positioning of supplies) found that the median ROI was 1.6–2.0. Other studies have examined specific responses or projects; one looked at the economics of early response in Kenya, Ethiopia, and Somalia for a population of 15 million people. It found that investment in early response and resilience could have saved US$4.3 billion over 15 years, with each dollar spent on safety nets and resilience resulting in net benefits of between US$2.30 and US$3.30. This, among a large and growing body of evidence, illustrates the potential of major investments in proactive climate risk management strategies, including early warning and adaptive safety net programs, to secure more resilient livelihoods for millions of farmers in low- and middle-income countries.

HOW: Mechanisms to achieve the outcome include:

- **Constructing a tighter continuum from humanitarian assistance to development processes.** Humanitarian assistance programs will need to increasingly incorporate climate resilience and risk reduction technologies and practices into interventions. Current impediments include policy and financing constraints, as well as technological bottlenecks and uptake challenges. These can be addressed through building stronger partnerships among finance, humanitarian, and science/technology institutions, to redirect humanitarian funding toward proactive risk management action (e.g. Box 9), and to co-design and implement a new climate-smart assistance paradigm.
- **Developing and improving early warning systems in climate risk hotspots.** A more consistent approach needs to be adopted, targeted to specific climate risks and different population sectors. Current limitations involve inconsistent and often sub-optimal practices in climate forecasting; a lack of identification of appropriate triggers for early action; and limited ability to reach women, youth, and other marginalized groups.[99] This can be addressed through development and adoption

of science-grounded standards and practices across meteorological and humanitarian institutions, as well as use of different communication mediums.

- **Aligning best practice safety net programs in climate risk hotspots.** National safety net programs will need to increasingly adopt a more holistic approach to emergency assistance and livelihood promotion, supported by contingent financing needed to adequately address climate risk. Current limitations include national policy and financing constraints. These can be addressed through establishing appropriate protocols and standards in this arena attached to adaptation and development financing.
- **Supporting early action with risk finance.** Increased risk financing will need to become available in order to be utilized in assistance programs at all levels. Currently there is insufficient finance accessible, and there is limited uptake of early action approaches. This can be addressed by building evidence of the ROI, and advocacy regarding early action approaches among key development and finance institutions and national governments (e.g. Box 10).

WHERE: Climate risk hotspots, including but not limited to the Middle East and North Africa, the Horn of Africa, Central America, and the Sahel.

SDGS SUPPORTED:

BOX 9. Ethiopia's Productive Safety Net Program[100]

Ethiopia launched the Productive Safety Net Program in 2005 to provide food and financial support to beneficiaries in exchange for public works. More than 8 million farming communities benefit from the program, which covers over 600,000 ha of land. The program implements participatory integrated watershed management and degraded ecosystem rehabilitation programs at both the landscape and smallholder farm levels. It has livelihood, ecosystem and agricultural outcomes.

BOX 10. Sovereign insurance: the African Risk Capacity initiative[101]

The African Risk Capacity (ARC) initiative provides national-level insurance against droughts to African Union member states. Participating governments prepare contingency plans prior to taking out insurance and subsequently determine how insurance payouts will be used when the insurance is triggered. By combining early warning and contingency planning with an insurance mechanism, ARC provides liquidity shortly after a catastrophic event, while the pre-planned activities ensure that payouts are used quickly and effectively, mitigating the detrimental impacts of disasters for the poor and vulnerable. ARC has paid out more than US$34 million to four drought-affected countries: Mauritania, Niger, Senegal and Malawi. The funds, disbursed ahead of the UN appeal, were used to deliver rapid relief to affected populations.

ACTION 2.2

Help farmers make better choices

CHALLENGE 2.2: Take climate services to scale by connecting 200 million farmers and agribusinesses to ICT-enabled bundled advisory services by 2030[102]

WHAT: The outcome envisaged is farmers get access to high-quality, actionable and real-time information, which equips them to manage climate risks, adapt to climate challenges, stimulate investment in technologies, and enhance their productivity.

WHY: The knowledge, tools, and technology to enable farmers to make better, climate-smart choices exist, and have been amply demonstrated in limited settings. The challenge is to make these resources available at scale, and equitably, to meet the needs of diverse beneficiaries (across gender and socioeconomic status) throughout the most vulnerable regions of the world. The challenge includes capacity, technical, and institutional elements. Whereas critical information and communication resources must rely on public institutions (such as meteorological services and agricultural extension services, rural radio, etc.), delivery of services at scale must at the same time fully leverage the potential of ICT and digital technologies in order to succeed. We must demonstrate the value and support the development of sustainable public-private partnerships that enable effective delivery of such integrated services.

HOW: Mechanisms to achieve the outcome include:

- **Strengthening capacity to provide actionable climate-informed advisory services to rural communities in climate risk hotspots.** Institutions need to be equipped to deliver quality information, advice, and assistance. Currently there is inadequate investment in capacity building and lack of consistent standards. This can be addressed through demonstration of successful service models, assessment of value, and promotion of new investment (including technical support).
- **Developing enabling agricultural insurance solutions for farmers and value chains.** Linking insurance to de-risk investment across the value chain is key to unlocking resources to enable better decisions that benefit all stakeholders. Currently there is limited opportunity for insurance solutions. To address this, technical improvements are needed to better design insurance to protect key investments while being offered at affordable prices. The investment case must be strengthened to entice new investment into the insurance market. Increasing attention to meso-scale insurance is appropriate to de-risk investment in smallholder agriculture by lenders and value chain actors.
- **Connecting the unconnected.** Expanding connectivity and access to ICTs, especially across Africa. This requires new investment in digital infrastructure, and policies that guarantee low-cost data access in rural areas. The rural agro- and climate-information gender gap needs to be bridged: meeting rural women's and youths' information needs will require attention to communication and technology channels. It also requires consideration of the tasks, information preferences and resources of different groups in rural areas.
- **Bundling services to reduce costs and enhance value.** Aggregated services can create economies of scale, reduce infrastructure costs, and enhance incentives for participation across the value chain from farmers to reinsurance. Currently many actors are operating on traditional, disconnected business models. This can be addressed through demonstration of successful integrated

services models and their value propositions, plus advocacy and support for new investment in this arena. Digital advisory services can be bundled with climate information, information on best practice, farmer-to-farmer networking (Box 11), and insurance and other financial services to incentivize adoption of climate-smart technologies and practices.

- **Enabling de-risking services through public-private business cases and regulatory environment.** Public-private partnerships and digital innovation in the agtech sector need to be incentivized to achieve scale. Public extension systems need to adapt to become digitally literate, ICT-enabled, and complementing and collaborating with the private sector. Open-data initiatives should be advanced, starting with government data assets. In the policy realm, support can be gained by promoting digital innovation as a cornerstone of driving climate action at national level.
- **Developing innovative public-private models to target and reach women, youth and other under-served groups** with information and services that address their needs and interests (Box 12), to take climate services to scale in an inclusive manner. Affordable and accessible financing models need to reach groups with less access to resources and digital technologies, and those in areas with poor infrastructure.

WHERE: Sub-Saharan Africa.

SDGS SUPPORTED:

BOX 11. Farm.ink: facilitating farmer-to-farmer livestock advice in Kenya

Farm.ink, a Kenya-based agtech start-up, seeks to connect geographically isolated farmers and provide research insights about livestock health. Through their platform, they facilitate a digital community, the Africa Farmers Club, which is a Facebook group that now has over 160,000 members. Through this platform, farmers can exchange knowledge about improving their livestock management practices, and tap into expert advisories. The Farm.ink team also built a chatbot on the Facebook Messenger platform to deliver dairy farmers information on productivity, markets, and livestock management. A survey by the project found that 92% of dairy farmers reported changing their farming practices based on information received through this service.

BOX 12. Is index insurance a safety net for women?[103,104,105,106]

Index insurance can increase the resilience of women farmers when gender differences are considered, with uptake rates often the same for women as for men. In cases of gender imbalance, many analyses finds that lower rates of financial literacy accounts for this difference. Other factors include degree of relevance to women's activities or crops, access to mobile phones, land ownership rights, education and household decision-making patterns.

ACTION AREA 3

REDUCE emissions through diets and value chains

Shifting food consumption patterns can not only reduce emissions but also improve health, food security and other environmental outcomes, providing multiple incentives for behavior change.[107] The IPCC Land Report estimated that the technical mitigation potential for changing diets in 2050 ranges from 2.7 to 6.4 Gt CO_2e/yr, with an economic potential of 1.8–3.4 Gt CO_2e/yr at prices of 20–100 US$/t CO_2.[108] Figure 9 shows the emission reduction possibilities of changes in consumption.

ACTION 3.1

Shift to healthy and sustainable climate-friendly diets

Food loss and waste leads to significant economic losses due to resource use inefficiency and environmental impacts. At the same time, the food supply chain contributes ~13.7 Gt CO_2e/yr, or 26%, of anthropogenic GHG emissions.[109] Of this, about 15–45% of food is lost or wasted.[54] Based on scenario modelling, decreasing global food loss and waste by 15% will reduce emissions by 0.79 to 2.00 Gt CO_2e/yr (Figure 9).[110] SDG 12.3 seeks to halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses. High-income countries tend to waste more food at the post-consumption stage while low-income countries tend to experience more food loss, especially in the production and storage stages.

ACTION 3.2

Reduce food loss and waste

"Delivering transformation of our food systems will save US$5.7 trillion per year in damage to people and the planet by 2030. Achieving it requires strong leadership and action to scale solutions from farm to fork—including reducing supply chain inefficiencies and supporting consumers to make healthy and sustainable dietary choices." [111]

– Diane Holdorf, Managing Director, Food & Nature, World Business Council for Sustainable Development (WBCSD)

ACTION 3.1

Shift to healthy and sustainable climate-friendly diets

CHALLENGE 3.1: Incentivize dramatic reductions in beef and dairy consumption in 15 high- and middle-income countries and all C40 cities by 2030

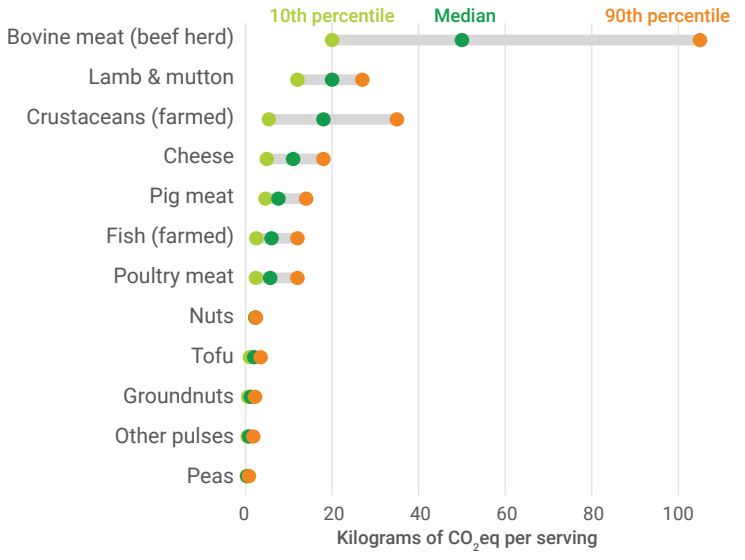
WHAT: The outcome envisaged is beef and dairy consumption reduced in high-income countries to support healthier and more sustainable diets. For example, the 2019 EAT Lancet report recommends reducing red meat consumption by 50%,[112] and reducing dairy consumption from a C40 average of 106 kg (220 kg in Europe) to 90 kg per person per year.[113] Consumers shift to protein sources with lower carbon footprints while improving their health.

WHY: Consumption of beef and dairy is the largest single driver of agricultural GHGs globally. Beef production contributes 2.9 Gt CO_2e/yr or 41% of total agricultural emissions, while dairy contributes about 1.4 Gt CO_2e/yr or 20%.[114] More climate-friendly protein sources are available: for 100 grams of protein, there are wide differences among protein sources, but also within a single protein source there is a wide range for production efficiency, as indicated by the 10th and 90th percentiles in Figure 12, suggesting that dietary shifts and increased production efficiency can make major changes in emissions.

Global demand for meat, including products other than beef, is expected to nearly double between 2005 and 2050, to 470 million tons.[115] Most of this demand (72%) will be in low-income and medium-income countries. Shifting globally to diets with less red meat has been estimated to reduce emissions by up to two thirds, reduce health costs and save up to 8 million lives.[116] The primary targets for reducing consumption-related emissions are those high- and middle-income countries where meat and dairy consumption is or will be high. In low-income countries, livestock will continue to play important social, economic and nutritional roles (Box 13). While the focus of this action is on animal products, we realize that for healthy diets many other considerations need to be brought in.

Countries where the future per capita consumption of meat exceeds 80 kg/year—the current average in industrialized countries—should be targeted for reduced consumption (about 15 countries, see Figure 13). Since 80% of global food consumption in 2050 is expected to come from cities, food systems transformation is also needed by city networks such as the C40 Cities Climate Leadership Group—a group of 94 cities around the world that have committed to action on both mitigation and adaptation.

FIGURE 12. **Greenhouse gas emissions for 100 grams of protein**



Source: Poore and Nemecek, 2018.[109]

BOX 13. The value of livestock to livelihoods vis-a-vis emissions reduction

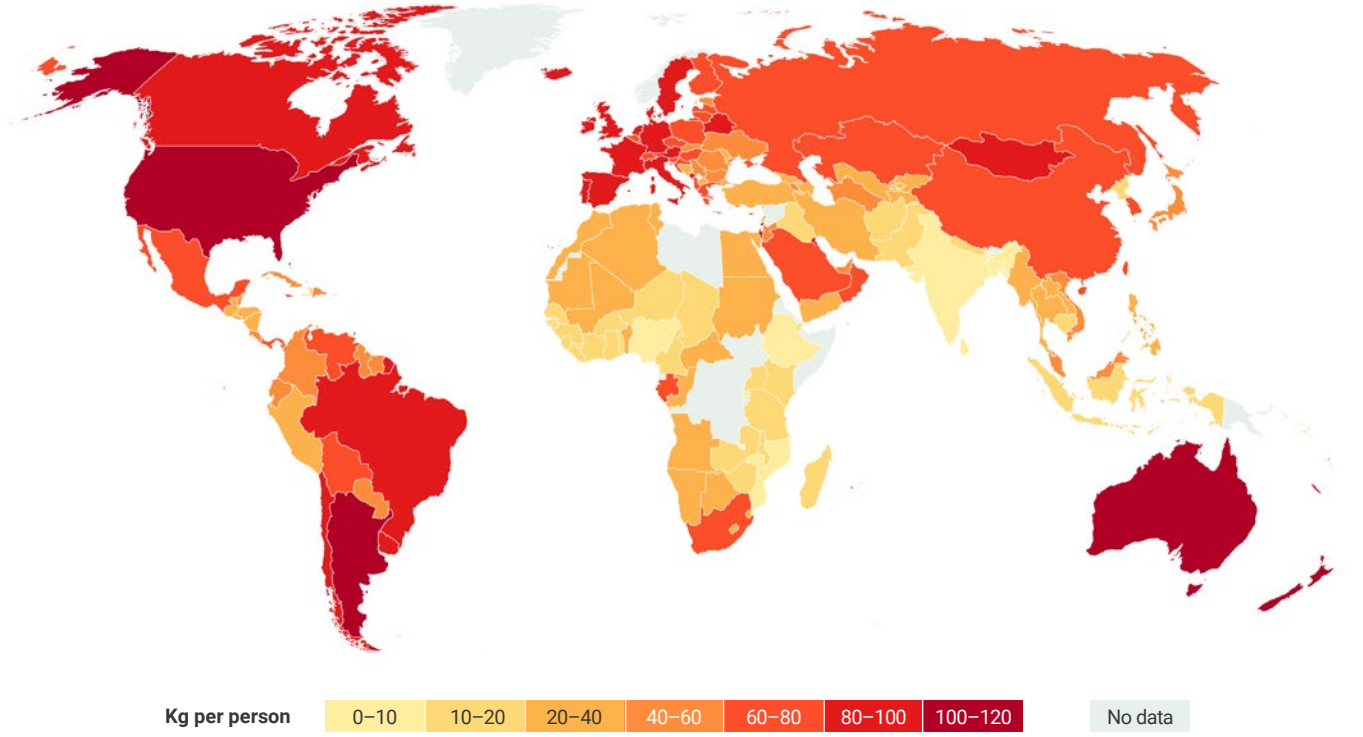
Livestock are crucial components of livelihoods in many parts of the world. For instance, in mixed crop-livestock and pastoral systems in Africa, livestock are *essential* for livelihood security.[117] In addition, in such parts of the world, protein in the diet is limited, with consumption levels far below those in high-income countries. Small gains in increasing emissions efficiency per unit of product in small-scale systems can nevertheless be made by improving production through improved feed, breeds, herd management and animal health, putting livestock development on a lower emissions trajectory than business-as-usual.[114] More significant opportunities for enhancing emission efficiency are likely in the shift to intensive production—although overall emissions usually increase—and in manure management. Improved feed can significantly reduce emissions per kilogram of meat or dairy, although feed production must not contribute to conversion of high-carbon stock lands.[118]

HOW: Mechanisms to achieve the outcome include:

- **Using public health promotions** to decrease meat consumption in high- and middle- income countries. Public health promotions can reduce the lack of awareness of the health implications of overconsumption of meat.
- **Supporting labeling and certification** of meat and other protein sources for GHG emissions, health and other environmental factors. Certification and payment for ecosystem services can become a key intervention for transitioning to systems that emit fewer GHGs.
- Developing incentives, enterprise support and public-private investment for innovation and production for **meat alternatives and protein sources** with smaller environmental footprints (Box 14).
- **Promoting awareness campaigns and social movements** via science-informed celebrities, champions, and media, driving alternative discourses (e.g., Greta Thunberg's "school strike for the climate" movement, C40 campaign, Meatless Monday movement)(Box 15).
- Exploring possibilities for **consumption taxes and subsidies** by identifying examples of cities that have either proposed or passed such measures, modeling potential impacts and trade-offs, and testing the acceptability of results to different interest groups. Political acceptability of these fiscal tools can be a challenge, but this can be overcome by demonstrating that the alternative is more costly.

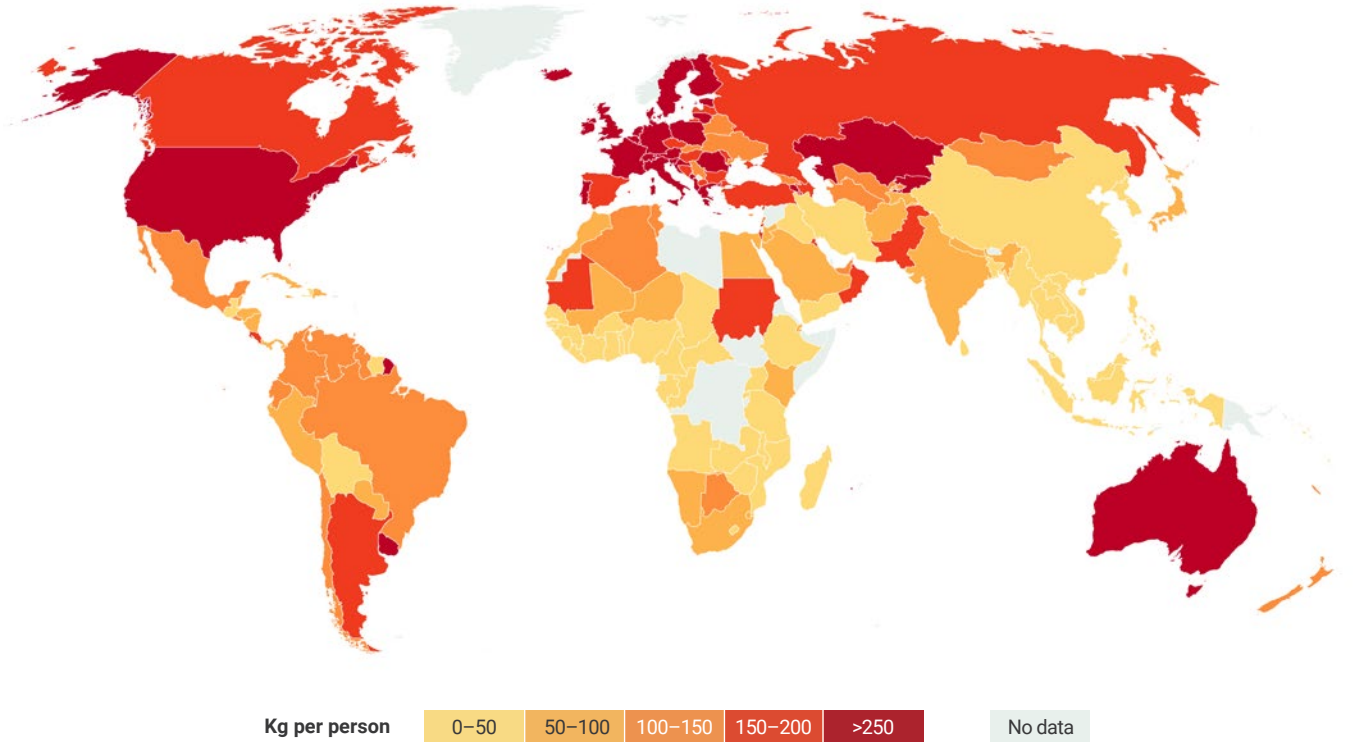
WHERE: Efforts should focus on those high- and middle-income countries and C40 Cities with current or expected high levels of meat and dairy consumption where overnutrition is contributing to obesity and chronic disease (Figure 13, Figure 14, and Figure 15).

FIGURE 13. **Per capita meat consumption, 2013**



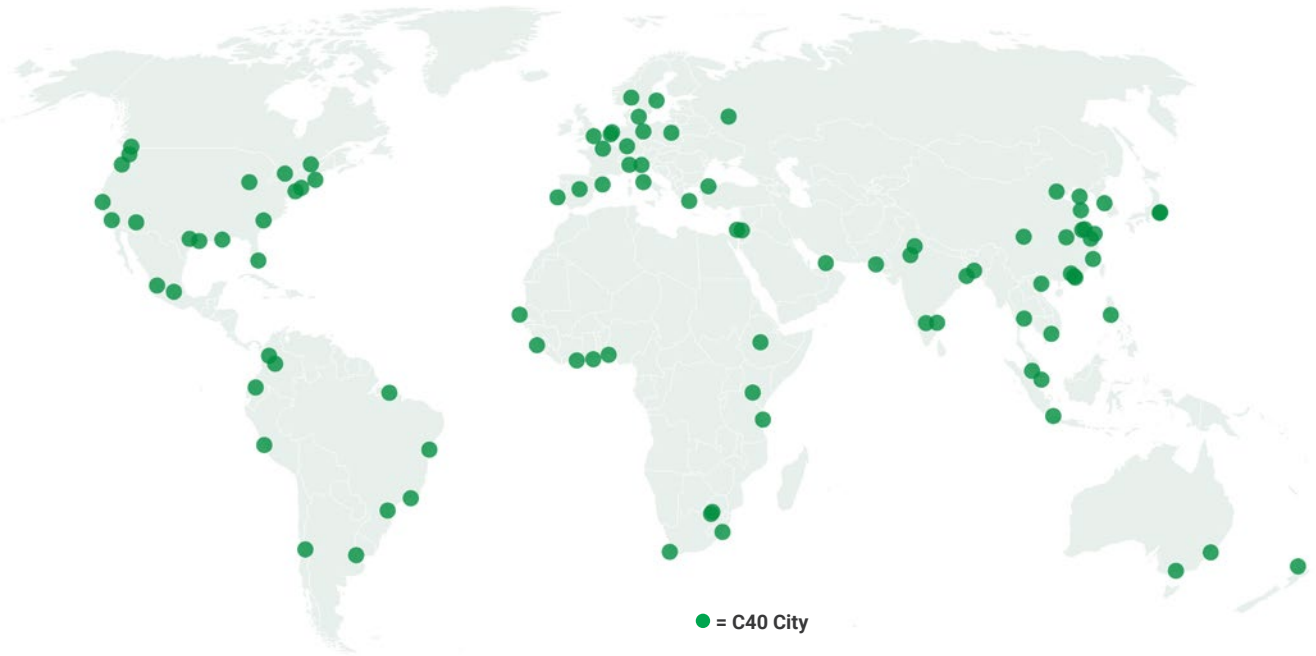
Source: Our World in Data, 2019.[119]

FIGURE 14. **Per capita milk consumption, 2013**



Source: Our World in Data, 2019.[120]

FIGURE 15. **C40 Cities**



Source: C40 Cities.[121]

SDGS SUPPORTED:

BOX 14. Plant-based meat alternatives

Viable meat alternatives that could satisfy demand for protein while dramatically reducing climate impacts have gained increasing attention. A number of companies have successfully established specialized markets in high-income countries,[122] and there is a growing interest and effort to supply alternative meats and proteins in low- and medium-income countries, illustrated by production of a fortified cassava porridge ("Power Gari") by women in Liberia, visions for small-scale alternative meat production in African refugee camps,[123] and philanthropic advocacy for protein equity involving vegetable-based and cultured animal products.[124] The increasing investment by major food and commodity companies in alternative protein start-ups clearly signals industry's belief in the potential for significant growth in this sector.

BOX 15. Meatless Monday movement[125,126]

Established in 2003, Meatless Monday is a non-profit public health initiative of Johns Hopkins, Columbia and Syracuse universities that is now active in 40 countries globally (Meatless Monday Global). The campaign aims to reduce meat consumption by 15% for human and planetary health. The initiatives ask schools, restaurants, hospitals, food companies, communities and individuals to commit to eating meat-free meals at the start of each week. Studies indicate that people are more open to trying healthy behaviors at the start of the week. Meatless Monday saves almost 2 t CO_2e/yr based on a typical American diet.

ACTION 3.2

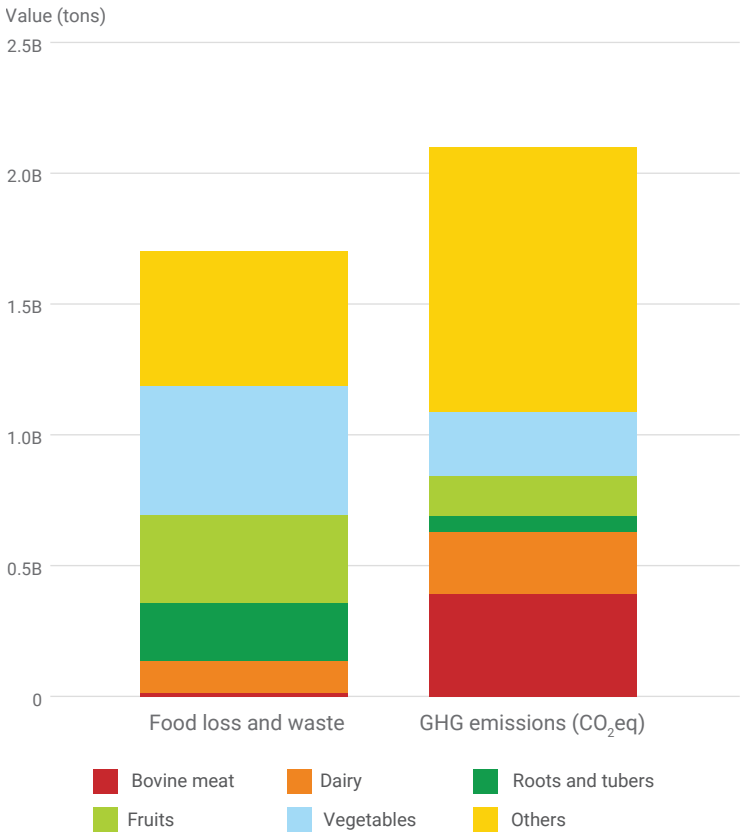
Reduce food loss and waste

CHALLENGE 3.2: By 2030, target 50% reductions in food loss and waste in five major supply chains where both greenhouse gasses and loss or waste are high

WHAT: The outcome envisaged is more efficient supply chains delivering food with minimal loss and waste. Demand for food production reduced proportionally, leading to lower production emissions.

WHY: In 2013, 1.7 Gt of food loss and waste (FLW) and 2.1 Gt CO_2e of FLW-associated GHG emissions occurred globally.[127] Numerous opportunities for reducing food loss and waste—as well as the associated unnecessary emissions—exist, so supply chain analysis to target the most important loss points in a supply chain and waste points among consumers is needed to identify priorities. Countries and supply chains can set targets for food loss and waste reduction based on the Champions 12.3 roadmap[128] and use the World Resources Institute Food Loss and Waste Protocol[129] to support consistent accounting. Following SDG 12.3, we set the target at 50% reduction and focus on the following five major supply chains where both GHGs and loss or waste are high: bovine meat, vegetables, fruits, dairy and roots and tubers (Figure 16). Industrialized Asia, and South and Southeast Asia are priority regions[127] (Figure 17). Care is needed to avoid using interventions that result in higher overall emissions, for example due to higher fossil fuel use.

FIGURE 16. **Major contributors to global food loss and waste and associated greenhouse gas emissions in 2013**



Source: Guo et al., 2019.[127]

HOW: Mechanisms to achieve the outcome include:

For reducing loss:

- **Using improved harvesting, processing and storage** in low- and middle-income countries (Box 16), including energy efficient cold chains. Initiatives and programs related to harvesting, processing and storage could be greatly scaled up in NDC and related national processes based on incentives for increased economic efficiency in the value chain. Making low-cost, easily replicated technologies available would give value chain actors incentives to switch practices. Support for entrepreneurship and public-private investment to stimulate innovation and large-scale uptake is needed to overcome this challenge.

For reducing waste:

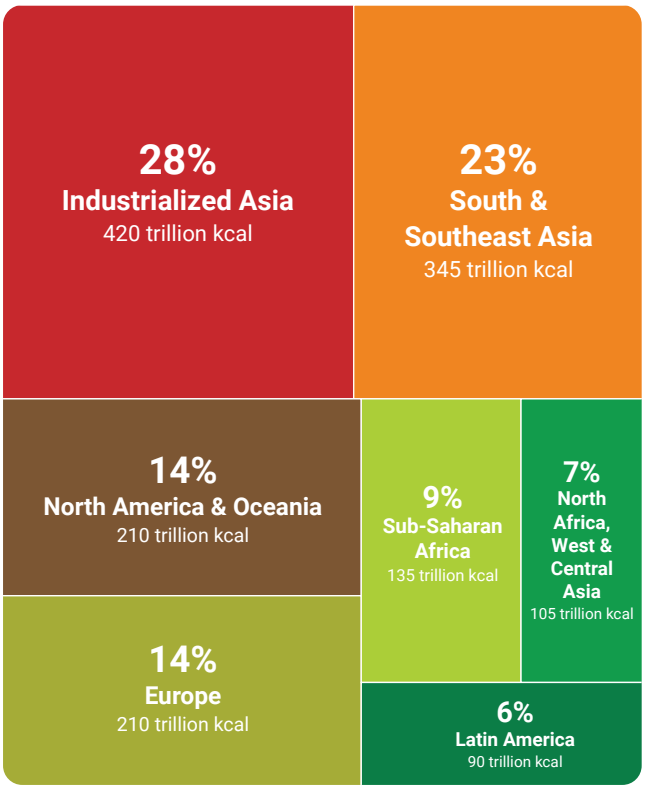
- **Developing early warning systems and information management for food demand and supply outlook,** e.g., "smart" marketing and information platforms, such as "just-in-time" production, or a farm-to-fork virtual marketplace to match food production and consumption. This may include optimizing inventory movement and warehouse storage, including procurement and supply chain policies. Such initiatives can reduce waste-related costs for value chain actors.
- **Organizing awareness campaigns** in school food programs and institutional food services.
- **Developing regulation and incentives** for smaller portions and reduced food waste, for example subsidies for innovations that recycle or higher costs for disposal of food waste.
- **Recycling and upcycling waste** between cities and peri-urban agriculture to support reuse of biowaste as renewable energy and higher value co-products in areas with high density livestock or urban waste disposal issues.

For both:

- **Creating incentives for companies to measure food loss and waste and implement food loss and waste policies** (Box 17), for example through success cases demonstrating possible cost savings, company reporting and disclosure to investors, or third-party monitoring.

WHERE: Target regions with high levels of loss and waste (Figure 17) and supply chains with high emissions, e.g., dairy, meat, rice, fruits and vegetables.

FIGURE 17. **Share of global food loss and waste by region, 2009 (100% = 1.5 quadrillion kcal)**



Source: Lipinski et al., 2013.[130]

SDGS SUPPORTED:

BOX 16. Reducing food loss in low-income countries

Reducing food loss can provide economic returns, while also reducing emissions. Approximately 10–20% of cereal production in sub-Saharan Africa is lost post-harvest, resulting in decreased farmer income and food insecurity.[131] Farmer investment in hermetically sealed cereal storage bags has greatly reduced cereal losses. The bags protect cereals and other crops from insect infestation and other potential damages, reducing post-harvest loss from an average of 14% to less than 1%, and reducing emissions proportionally. Producing the bags requires relatively low upfront costs and farmers can recoup their investment in the bags within a single farming season.

BOX 17. Reducing food waste[132]

IKEA, a global furniture retailer, has over 400 stores and almost one billion visitors each year, including 680 million visitors who in 2018 spent €2.15 billion in IKEA's food outlets. In 2016 IKEA launched the "Food is Precious" initiative, setting a target to reduce its food waste by 50% by August 2020. Notable actions included: 1) using a smart scale system to monitor food waste in four IKEA stores, resulting in a 23–54% decrease in food waste over six months; 2) appointing "Food Waste Champions" in each store to motivate colleagues at work and home; and 3) appointing a "Country Implementation Responsible" person for targeted markets to lead implementation and support co-workers. IKEA experienced a 20% reduction in food waste within 12 weeks of starting the food waste-reduction initiative and found that additional investments mostly had a 20-week payback period. IKEA plans to also address food loss and waste with its suppliers and to encourage consumers to reduce food waste at home.

ACTION AREA 4

REALIGN policies, finance, support to social movements, and innovation

To achieve the "Rerouting," "De-risking," and "Reducing" actions, we propose several cross-cutting actions, for policies and institutions, finance, social change and innovation.

Creating an enabling environment that incentivizes action, fosters innovative solutions and builds a level playing field is essential for the transformation of food systems under climate change. Arguably, policy and institutional actions are core to achieving all other actions.

There is a considerable finance gap between what is currently available and what is needed for low- and middle-income countries to adapt their food systems to climate change. Climate is tightly associated with almost any activity in the food system, from finance for GHG mitigation and adaptation, to reducing waste. Business opportunities in the implementation of the SDGs related to food could be worth over US$2.3 trillion annually for the private sector by 2030; the investment required to realize these opportunities is approximately US$320 billion per year.[133]

ACTION 4.1

Implement policy and institutional changes that enable transformation

ACTION 4.2

Unlock billions in sustainable finance

> "Never doubt that a … group of **thoughtful, committed citizens can change the world;** indeed, it's the only thing that ever has."
>
> —*Margaret Mead*

While climate change impacts are already being felt, youth in particular will bear the brunt of climate change. Social media has helped to spread awareness and sentiment among youth, facilitating the rise of youth-centered social movements, such as the #FridaysForFuture campaign. #FridaysForFuture, started by the eloquent and outspoken Greta Thunberg, has perhaps done more to shift opinions and garner support for action to combat climate change than almost any number of technical reports. The movement is also creating a cohort of citizens who will be active participants in democracy and in future policy decisions.[134] As agencies working on climate change, we need to look for ways to support such social movements, for example through knowledge co-generation, forging connections between stakeholders, and fostering platforms for interaction and education in today's interconnected, globalized world.

ACTION 4.3

Drive social change for more sustainable decisions

There are many actions that can be taken to align food systems with the 2°C pathway, as well as to facilitate adaptation and spur development (see e.g., FOLU 2019,[135] IPCC 2019[2]). But to be successful, all of these actions have to be undertaken in an environment that enables innovation across all food system actors—that's all 7.7 billion of us. Agricultural research for development and innovation systems are often fragmented, inefficient, overly supply-based, and siloed. Innovation can be hampered by fear of failure, a short-term orientation, the existence of inappropriate or perverse incentives that may result in redundancy and duplication, and a focus on "publish or perish." In such circumstances it is difficult to deliver end-to-end, sustainable solutions to problems, and to deal with power relations that may exclude disenfranchised groups from benefiting.

ACTION 4.4

Transform innovation systems to deliver impacts at scale

ACTION 4.1

Implement policy and institutional changes that enable transformation

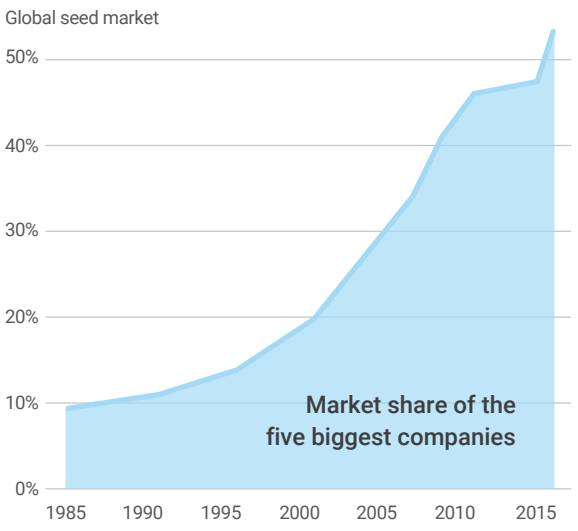
CHALLENGE 4.1: By 2025, realign US$300 billion of agricultural subsidies to a climate change agenda in 16 countries,[136] improve the "ease of doing business" in 24 sub-Saharan African countries,[137] and significantly improve the readiness score of the ND-GAIN Index in 49 countries[138]

WHAT: The outcome envisaged is policy reforms take place so that public subsidies incentivize private sector investments that support sustainable, inclusive, healthy and climate-resilient food systems (Box 18). The operating environment for businesses, especially small- and medium-sized businesses, has improved so that obstacles to accessing markets for small-scale producers are reduced. Trade barriers are being tackled in order to promote adaptation (Box 19), and power disparities in the food sector have disappeared.

In seeking a single indicator of commitment to adaptation, we suggest use of the ND-GAIN Country Index. This index summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience.

WHY: Firstly, better targeting of public subsidies to incentivize private sector investment can be a game changer in financing the transformation of the rural world. World Bank studies demonstrate that subsidies often fail to promote resilient agricultural systems and lead to negative externalities, including environmental damage.[139] Secondly, private sector action is fundamental to "Rerouting," "De-risking" and "Reducing"—thus the focus on improving the business environment. Thirdly, trade is fundamental to large-scale adaptation actions when there is a climate-related failure of a food basket. And fourthly, the global food system has come to be dominated by a small number of very large companies (Figure 18),[140] and thus policy actors need to address issues of power, and how those issues impact producers' and consumers' access to the services and products they need to build their livelihoods. This also means attention to local power dynamics related to gender, social inclusion and youth.[11,141]

FIGURE 18. **Concentration trends in the seed industry, 1985–2016**



Source: Bonny 2017.[142]

HOW: Mechanisms to achieve the outcome include:

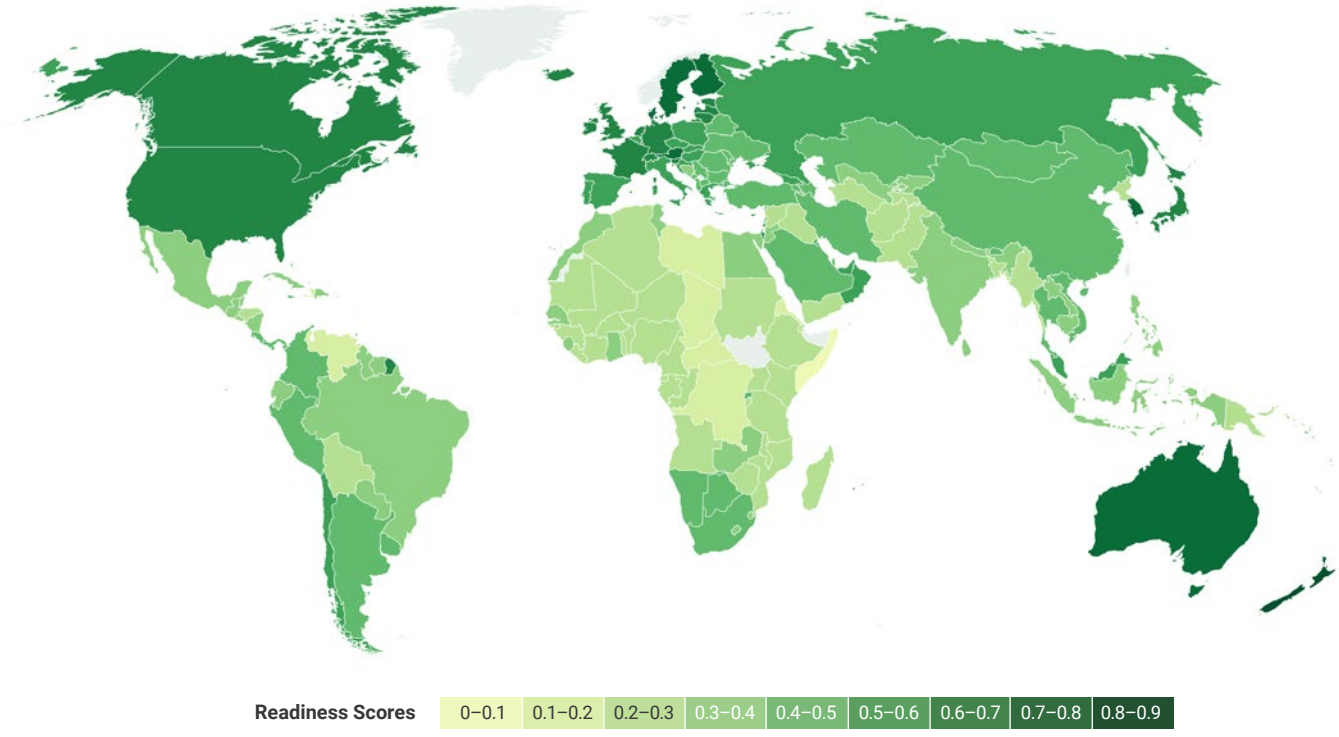
- **Participatory scenario building** with policy actors and stakeholders (including producers and consumers). There are diverse perspectives on what is needed in food systems to achieve sustainable, inclusive, healthy and climate-resilient food systems. Participatory scenario building has been used successfully to build legitimacy, ownership and trust for

policy agendas that tackle bottlenecks, enhance opportunities and stimulate action.[143] Given unequal power dynamics, policy processes must ensure effective participation by marginalized groups.

- **Tailored support to countries** to take on a reform agenda. This activity involves designing and executing smart information and communications strategies that lay the ground for consensus for reform, technical assistance to countries to identify potential for policy reform and priority actions for implementation, and review of possible mechanisms for implementation.[111] Reform would aim at using subsidies wisely, improving the operating environment for businesses, especially small- and medium-sized businesses, reducing obstacles to accessing markets for small-scale producers, tackling trade barriers to promote adaptation, and tackling power inequalities.
- **Advancing gender equality and social inclusion**. The views of women, youth, indigenous peoples and marginalized peoples need to be integrated into decision-making, finance and policy bodies at all levels. Working with women's, farmer and youth organizations is another important channel. Women should be recognized as active agents in climate adaptation and mitigation, rather than as vulnerable victims. Inequalities in rights, resources, decision-making and opportunities need to be taken into account. Attracting youth to participate in food value chains is part of the enabling environment and is likely to require re-skilling and capacity building in new areas as technologies evolve and population distributions change.[141]
- **South-South, North-South and North-North learning on policy successes**. Peer-to-peer learning can be extremely instrumental in driving policy change.[144,145] Opportunities for countries to learn from each other and to share knowledge and experiences should be provided.

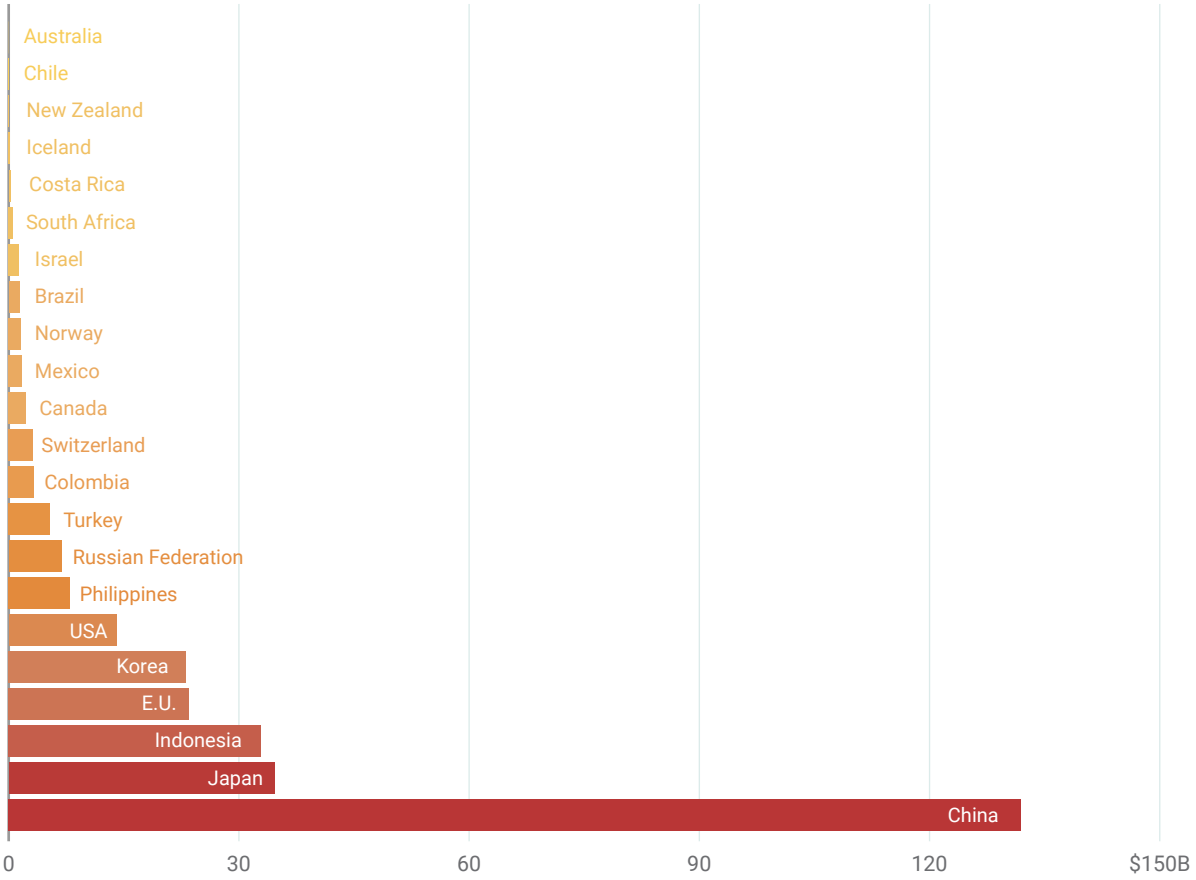
WHERE: Policy action is needed in all countries, as current performance on climate policy is poor (Figure 19). The focus for improving ease of doing business is sub-Saharan Africa, as it is the region with the lowest average. Retargeting subsidies will be in countries with the highest market price support (Figure 20) and strategic countries where high subsidies are incentivizing an inefficient use of resources.

FIGURE 19. 2017 worldwide ranking by readiness of the ND-GAIN Index, higher scores are better



Source: Notre Dame Global Adaptation Initiative.[146]

FIGURE 20. **Market price support in agriculture in OECD countries and key partners**



Source: OECD, 2019.[147]

BOX 18. Better targeting of subsidies

From 2015 to 2017, support programs and policies in 51 countries provided approximately US$570 billion annually in public support to agricultural producers. World Bank studies have demonstrated that subsidies often fail to promote resilient agricultural systems and lead to negative externalities, including environmental damage. For example, production subsidies requiring production of specific commodities or restricting land to the production of certain crops can induce economic inefficiency, limit crop diversification, compromise productivity and resilience through water and land degradation, and lead to high emissions. Therefore, better targeting of these public subsidies to incentivize private sector investment can be a game changer in financing the transformation of the rural world and actions to address climate change. This needs to take place alongside more stringent implementation of polluter-pays principles and carbon taxes within food systems.

BOX 19. Promoting free and open trade

When it comes to food production, climate variability can increase disparities between short-term demand and supply among regions. So long as this variability is not correlated across regions, trade flows, combined with storage, could effectively diversify climate risk on a global scale, meaning less volatility in food prices. A rapidly changing climate and volatile markets added to trade restrictions proliferation could put the food security of millions at risk.[148] Therefore, polices that promote free and open trade should be incentivized. The current state of international trade negotiations is moribund; but trade to facilitate adaptation to short-term climate variability related to climate change might be a way to restart negotiations.

ACTION 4.2

Unlock billions in sustainable finance

CHALLENGE 4.2: Unlock US$320 billion in public and private capital per year to realize business opportunities in the implementation of the SDGs[133]

WHAT: The outcome envisaged is financiers reorient and leverage the public and private capital flows needed to sustainably finance the transformation to low-carbon and climate-resilient food systems that meet global food needs, the SDGs, and the objectives of the Paris Agreement.

WHY: Global food systems will need to produce food more efficiently and sustainably to feed a growing population, achieve the SDGs, and meet the 2°C climate commitments of the Paris Agreement. Governments, food and agriculture companies, and public and private investors need to better identify and address the numerous climate-related risks they face. However, this can also be an inflection point to take advantage of new investment opportunities that the transformation to sustainable, low-carbon and resilient food systems presents. Addressing core market failures to move sustainable land-use financing into the mainstream will be required to unlock the private investment needed.

HOW: Mechanisms to achieve the outcome include:

- **Creating investment opportunities** that are attractive to public and private investors. This requires incorporating climate considerations into public investment appraisals; integrating sustainability and mainstreaming environmental, social and governance standards in investment decision-making processes; scaling up green financing linked to climate outcomes; embedding the external costs of unsustainable food systems into business-as-usual decision-making, creating market incentives for new sustainable opportunities and supporting market-building interventions; blending finance to develop a deeper pipeline of bankable projects and catalyze private investments in new markets and business models (Box 20); and developing digital solutions to support pipeline development and new standalone investment opportunities.
- **Building capacity to accurately assess risk and deploy appropriate risk-mitigating mechanisms**, by equipping investors with the data and risk tools needed for better risk assessment, and utilizing mechanisms such as blended finance to de-risk and catalyze private capital.
- **Improving intermediation to match risk-return profiles to different sources of private capital**, by developing market-accepted climate valuation methodologies, and simpler and standardized products; promoting aggregation and securitization to convert investment products into securities marketable to a wider pool of investors with different risk-return appetites (Box 21); fostering deal matchmaking platforms to facilitate transactions between a pipeline of investable projects and pools of investment capital; and shifting the investor mentality to take advantage of the growing momentum in blended finance to participate in less traditional asset classes and markets.

WHERE: Global, but targeting small-scale producers.

BOX 20. AGRI3 Fund[139]

The AGRI3 Fund, launched in October 2018, is a public-private partnership that aims to unlock US$1 billion for forest protection and sustainable agriculture, and to bridge the gap between the needs of farmers and the limitations of banks. The fund is providing local and smallholder farmers with access to financing and the skills to transition to sustainable and climate-smart agriculture, by blending public and private sources to enable projects that would otherwise not materialize because of their risk profile. The fund consists of a finance fund and a related technical assistance facility. With commercial banks, the finance fund co-invests capital in sustainable agricultural supply chains. The fund also provides a range of different de-risking financial instruments. The technical assistance facility provides support for pipeline development, monitoring and evaluation, and capacity building.

BOX 21. Tropical Landscape Finance Facility[139]

The Tropical Landscape Finance Facility (TLFF) offers long-term loans to projects in renewable energy and sustainable agriculture whose outcomes include improved livelihoods, reduced deforestation, better agricultural efficiency, and restored lands. TLFF consists of a loan facility that funds early-stage projects using credit-enhancing instruments of development investors to leverage private finance. Once the projects reach maturity and generate sustainable cash flows, they are aggregated and repackaged as medium-term notes sold by BNP Paribas to patient capital investors in tranches according to risk capacity, with the objective of reaching US$1 billion. This structure helps to recycle loan capital for further lending activity. In 2018, TLFF launched its inaugural transaction: a US$95 million loan to help finance a sustainable natural rubber plantation in two heavily degraded landscapes in Indonesia. This will enable PT Royal Lestari Utuma to train, employ and provide stable revenues to thousands of farmers while also protecting tropical rainforest on the plantation.

ACTION 4.3

Drive social change for more sustainable decisions

CHALLENGE 4.3: Reach 10 million young people by 2025 through science-based social movements to catalyze climate action in food systems[149]

WHAT: The outcome envisaged is individuals making choices that are beneficial for their own health and the health of the planet. Shifts to more sustainable decisions that are appropriate for different economic and sociocultural circumstances, supported by science, regulatory frameworks and social norms.

WHY: For a transformation in food systems to take place, behavioral change on a large scale is necessary, by producers and consumers alike.[150] Social movements have the power to trigger transformation processes,[44] for instance by promoting behavioral change by businesses by creating new social norms (Box 22). At the same time, policies that encourage new behaviors can promote changes in consumer habits (Box 23). This action is about linking science to social movements to support transformation. It includes using behavioral science to design interventions, translating scientific knowledge for a broad audience, communicating messages in innovative ways, bringing youth into the discussion, and improving education in order to raise awareness.

HOW: Mechanisms to achieve the outcome:

- **Increasing awareness** of sustainability concerns. Coupled with powerful platforms for two-way dialogue between disparate actors, this can provide a wealth of opportunities to drive behavior and change global agendas.[151,152,153,154]
- Focus on **changing actual behaviors** beyond raising awareness. In order to incentivize these changes, there is a need to integrate **behavioral science into the design of interventions** to understand, predict and mobilize social change around issues such as dietary choices including purchasing behavior and consumption patterns. This can be complemented by conducting **behavioral diagnostics** of successful cases to extract lessons for replication and scale.
- **Translate** scientific knowledge into concrete messaging that can inform social movements. A gap exists between scientific research results and the generation of knowledge able to support these kind of movements. In order to bridge this gap, there is a need to identify target behaviors that producers and consumers are likely to adopt and develop tools to **prioritize** behaviors that matter most for climate outcomes.
- Catalyze **innovative volunteerism** among rural youth to capitalize on their skills and experience for societal and individual benefit. **Youth** need to become a **pivotal point** in transforming food systems under climate change. Radical changes need new perspectives and voices that can speak freely about the changes needed.
- Improve **education** at primary, secondary and tertiary levels with appropriate curricula and tools to raise awareness of food system and climate interactions. Lack of involvement from education ministries in climate change issues have precluded the insertion of relevant climate change material into curricula. Infomediaries to reach parents and other adults need to be part of the education strategy.

BOX 22. Utilizing the power of social movements to modify behavior[155,156]

Over the last few years, some North American cities have seen considerable changes in local food systems, brought about in part through social movements and food activism. The "eat local" movement is an example. There is little doubt that consumers can foster social change but this needs to include much deeper engagement in governance processes at all levels in food systems. Science has a role to engage and ensure social movements are science-based.

BOX 23. Progress on plastic waste: a case where traditional and social media have eased the pathway for business strategies and public policies[44]

Citizen-led social movements and social media can create new social norms that can promote behavioral change. Plastic waste reduction in several countries demonstrates the power of social and traditional media and social movements to drive change. For instance, awareness on plastic pollution in the ocean boomed in 2018. Awareness was promoted through evidence-based advocacy organizations (e.g. Ellen McArthur Foundation), television shows (e.g. Blue Planet 2), and videos shared on the Internet (e.g. a viral video filmed by a biologist of a turtle affected by ocean plastic). The increase in awareness drove the adoption of commercial strategies and public policies on single-use plastics such as bans and levies, demonstrating that a short-term spike in interest among a large enough group can be a sufficient hook for more lasting responses from governments and businesses.

ACTION 4.4

Transform innovation systems to deliver impacts at scale

CHALLENGE 4.4: By 2025, significantly change the approach of public agricultural research for development, with at least 50% of public investment in this research providing end-to-end solutions that support meeting the SDGs related to food

WHAT: The outcome envisaged is the global public agricultural research for development community working as one on food system innovations, with coherent and joined-up research design, implementation and funding strategies that are addressing the needs of the many.

WHY: Globally, over US$30 billion a year is spent on agricultural research and development.[157] These resources drive growth in the agricultural sector and have the potential to catalyze innovation for a transformation in food systems under climate change. Imad Moosa argues that while published research has exploded in quantity, quality has declined, as measured by societal impact, among other things. The "publish or perish" maxim drives researchers to focus on their own curriculum vitae rather than societal needs.[158] Transforming innovation systems to deliver impacts at scale, including end-to-end solutions for actors in food systems, is a priority and will involve rethinking how research and innovation are part of a wider systemic change.[159]

However, there needs to be a balance between very demand-driven research that has impact in a few years and longer-term research to solve important, difficult bottlenecks. For example, plausible agricultural development pathways with mitigation co-benefits deliver only 21–40% of the needed mitigation from direct agriculture emissions.[160] We conclude that one priority for research is possible breakthrough technologies to reduce emissions (e.g., dietary supplements that reduce methane production in the rumen).[161] Some promising innovations on the horizon (Box 24) can be fostered through highly targeted efforts in technology development.

BOX 24. "Wild futures": Technologies for transforming food systems[162]

A recent inventory found new and emerging technologies all along the value chain, from production to consumption, and across the food system, in the domains of cellular agriculture, digital agriculture, food processing and safety, gene technology, health, inputs, intensification, replacement food and feed, and waste reduction. For the top technologies that are near-ready for deployment and have high potential for impact, investment in their accelerated dissemination and implementation will be critical for achieving the food-related SDGs. We urgently need novel methods to integrate these options into current food systems, as well as a better understanding of what might affect their uptake to scales that can be transformative. We will need innovative and gender-responsive institutional arrangements to ensure that advanced technologies can be accessed by small-scale agricultural producers.

HOW: Mechanisms to achieve the outcome include:

- **Breaking out of the research comfort zone**: connecting capital providers, researchers, and end-users to provide a research-for-development "ecosystem for innovation" that enables stakeholders to accelerate the transformation needed in food systems. National and international research funding bodies can incentivize and encourage systems of innovation that focus on changing ways of engaging and doing the business of research. Box 25 illustrates how partnerships can help to achieve scale.
- Changing **incentive structures**, **management and governance** for researchers and the public sector in agricultural research and development systems to value the generation of societal outcomes, thus ensuring greater uptake of research results by food systems stakeholders.
- **Transforming approaches to priority setting** in policy-making processes, via joined-up foresight, participatory scenarios, and ex ante and ex post analysis, which will enable better decisions in the context of climate change. Especially important will be to analyze which technologies and practices are resilient, to whom, and where, in the face of 2°C of warming, as well as determining where and how agriculture "fits" (sectorally, geographically, considering a gender dimension).
- **Dealing with the gender gap.** The gender gap in technology adoption needs to be overcome. For example, in many cases women are not adopting improved seed varieties or new technologies due to gender-related barriers to accessing finance, fertile land, training, information, and markets (Box 26). Innovative models are needed for gender-responsive technologies and practices that reduce women's workloads and increase their production while supporting household nutrition and increased market options.
- **Identifying key priorities for action research** and allocating resources against these priorities. In Table 2, we offer a preliminary list of research questions that address knowledge gaps in relation to each of the actions proposed in this report. Addressing these gaps could provide the knowledge basis for transformation.

WHERE: The focus should be on national and international research funding bodies in order to prioritize funding for research able to find end-to-end solutions that support meeting the SDGs related to food.

BOX 25. Partnering to scale-up drought-tolerant maize for Africa

Recognizing the challenges that maize-based systems were facing across Africa, the Bill and Melinda Gates Foundation and other donors invested in the Drought Tolerant Maize for Africa (DTMA) initiative, which built a public-private partnership for developing improved genetics in maize that would help farmers stand up to drought. Researchers identified key traits that generated greater resistance to drought in maize, and successfully bred over 200 new varieties of maize that could maintain production despite irregular or low levels of rainfall. In 2014 alone, the project supported production of nearly 54,000 tons of certified drought-tolerant maize seed benefiting an estimated 5.4 million households (43 million people) across the 13 focus countries. The project involved national and international research agencies, and numerous local and larger seed companies.

BOX 26. Gender and seed systems[163]

Women are not adopting improved seed varieties for many reasons. For example, the land women farmers have access to tends to be less productive and improved seed varieties may not be adapted to the kind of soil fertility found in female farmers' fields. Innovating with men and women farmers to select and test new varieties and hybrids, as well as related seed production techniques, is needed for successful adoption. Strengthening informal seed networks and building a connection between the formal and informal seed sectors is also crucial to providing farmers with genetic diversity and other farming requirements. Women can be targeted as sources of local seed and as a means of seed distribution since they may have larger networks—they often retain ties in their parents' villages while creating new connections where they are married. Supporting women's role in localized informal seed networks and the conservation of genetic resources supports local knowledge and cultural diversity as well.

TABLE 2. Key priorities for action research

TRANSFORMATIVE ACTIONS		PRIORITY RESEARCH QUESTIONS
ACTION 1.1	**Ensure zero agricultural land expansion in high-carbon landscapes**	What are the methods, tools and policies to incentivize better transparency and accountability in commodity supply chains? How can these be scaled?
ACTION 1.2	**Enable markets and public sector actions to incentivize climate-resilient and low emission practices**	What are the factors that can support rapid scaling out of climate-resilient practices and technologies, taking into consideration context-specific needs?
ACTION 1.3	**Support prosperity through mobility and rural reinvigoration**	What are the opportunities for livelihoods development in rural areas when farming is no longer viable under climate change?
ACTION 2.1	**Secure resilient livelihoods and value chains through early warning systems and adaptive safety nets**	How can the "last mile" challenge in the delivery of climate services be overcome?
ACTION 2.2	**Help farmers make better choices**	How can farmers leapfrog traditional agricultural development pathways through digitization?
ACTION 3.1	**Shift to healthy and sustainable climate-friendly diets**	What mechanisms are most effective (and in which contexts) to transition towards healthy and sustainable diets, including taxes, subsidies, labeling, awareness campaigns, etc.?
ACTION 3.2	**Reduce food loss and waste**	What are the bottlenecks that deter reduction of food loss and waste, and how can these bottlenecks be overcome?
ACTION 4.1	**Implement policy and institutional changes that enable transformation**	How can entrenched views and political realities be addressed to catalyze reform in the agriculture and food sectors in countries?
ACTION 4.2	**Unlock billions in sustainable finance**	What are the best practices to develop bankable projects for food systems transformation?
ACTION 4.3	**Drive social change for more sustainable decisions**	What are the behavioral factors for replicating and scaling social change?
ACTION 4.4	**Transform innovation systems to deliver impacts at scale**	What are the best practices to improve knowledge generation processes to support the transformation agenda?

CHAPTER 4

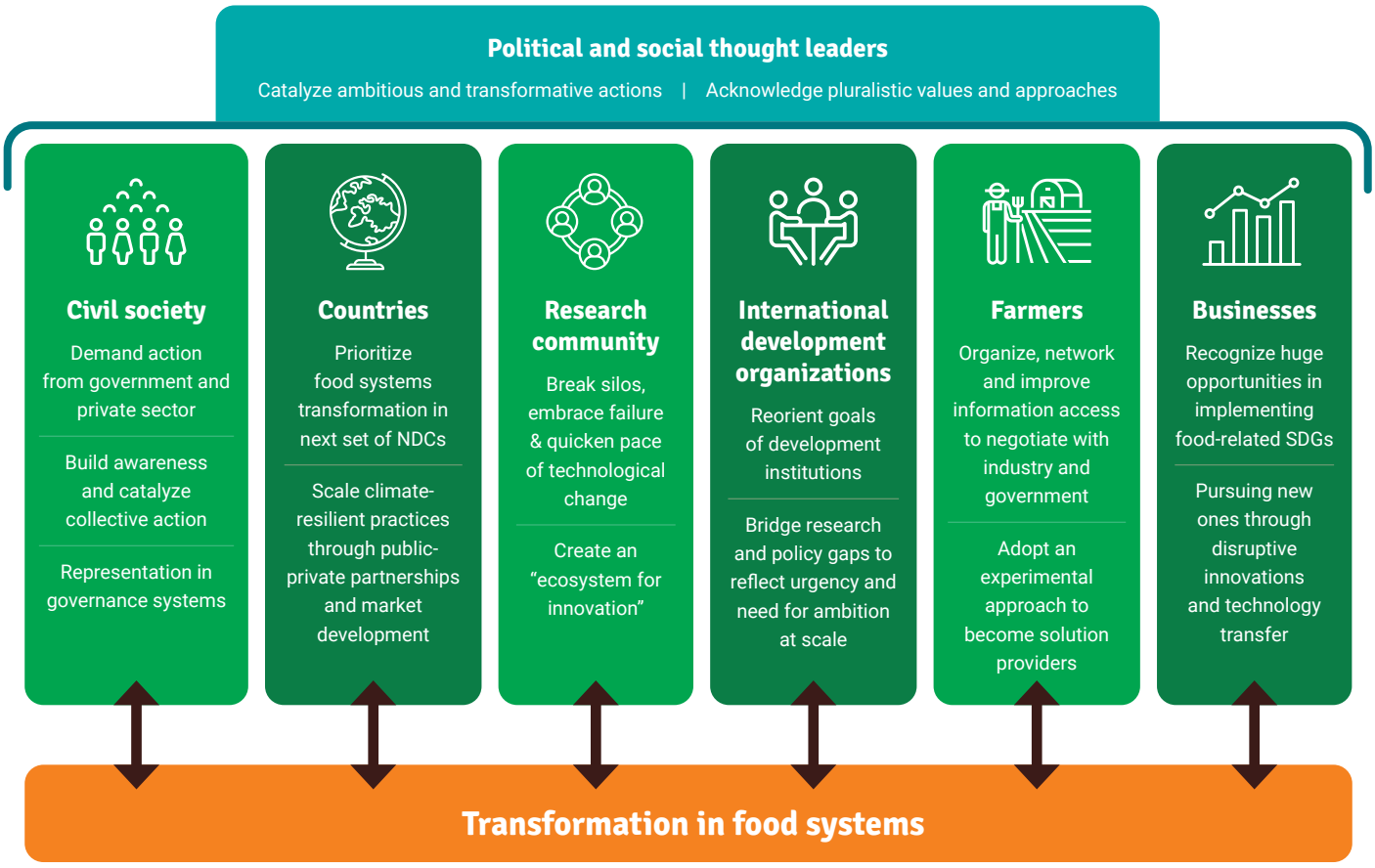
Playing your part in fixing food systems

With only 10 cropping seasons left to achieve the SDGs in some countries, the need for ambitious action has never been more urgent. The onus for action falls not only on countries themselves, but also on the different stakeholders in food systems. We believe that a concerted effort by different stakeholders can catalyze a transformation, and thus we have identified priorities for different stakeholder groups to play their part (Figure 21).

Countries: In the lead up to the second round of NDCs, there is growing evidence that the Paris Agreement's goal of containing warming to 2°C, let alone 1.5°C, will not be met with the current set of commitments and action. Actions to transform food systems in countries need to be a priority in the next set of NDCs based on context-specific needs and readiness for implementation. Opportunities include developing markets and public-private partnerships to scale climate-resilient practices, establishing safety nets to secure livelihoods, upgrading rural infrastructure and enhancing the quality of life in rural areas, ending perverse incentives, and protecting high-carbon landscapes.

Research community: The research community needs to break silos, embrace failure and quicken the pace of technological change, providing end-to-end solutions to meet the needs of all stakeholders in food systems. This involves developing an "ecosystem for innovation" that is fit for purpose and goes beyond traditional comfort zones. This would include research in crop/livestock breeding, digitization, finance, business models, behavioral change, etc., providing solutions with the power to catalyze a transformation. Changes are needed to incentive structures, management and governance for researchers and the public sector in agricultural research for development systems in order to make this vision a reality.

FIGURE 21. **Stakeholder groups needed for a transformation in food systems**



International development organizations: Business-as-usual approaches to development are not going to realize a transformation. There is a need for NGOs, international organizations and donors to reorient the goals of development institutions and bridge research and policy gaps in a way that reflects the urgency and need for ambition at scale. Major opportunities include redirecting humanitarian aid to building adaptive safety nets, facilitating South-South, North-South and triangular cooperation strategies to reach scale, facilitating the development and deployment of public-private partnerships, and advancing gender equality and social inclusion. There is a need for international development organizations to show leadership on emerging topics such as sustainable diets and food loss and waste, providing tailored solutions to countries.

Farmers: Farmers continue to be on the front line of climate change and other challenges for food production in a changing global economy, but there is a possibility to turn these challenges into opportunities and for farmers to be the solution providers catalyzing a transformation in food systems. This requires an experimental mindset among farmers and efforts to strengthen social capital and collaboration, which will enable farmers to better negotiate with industry and government and make their voices heard in decision-making processes. Work with farmers needs to take into account the priorities and opportunities of different farmer groups: small-scale farmers, women, youth, and marginalized and indigenous farmers.

Businesses: Business opportunities in implementing the SDGs related to food are valued at around US$2.3 trillion per year by 2030, representing a huge opportunity for current businesses and for entrepreneurship in the sector. Realizing these opportunities requires investment to the tune of US$320 billion per year. Businesses should take cognizance of the opportunities and pursue new ones through disruptive innovations and technology transfer. Opportunities include increasing transparency and accountability of major commodity supply chains, expanding access to credit for implementing climate-resilient practices, sustainable micro irrigation, risk-based insurance mechanisms, reducing food loss and waste, and ushering in digitization with bundled services for farmers. Financial institutions need to tighten minimum standards, set up blended finance solutions with public partners at scale, and provide access to knowledge, network and financial products that reward the transformation.

Civil society: The role of civil society in demanding climate action has been in the spotlight over the last year, from climate strikes in schools to the extinction rebellion. Climate action is a key concern for an increasing number in the electorate. Social movements will need to continue their role, to demand ambitious action from governments and the private sector, build awareness, and foster collective action among communities. At the same time, greater civil society representation in governance systems can not only raise ambition but also support implementation, in areas including promotion of sustainable and healthy diets and reducing food loss and waste.

Political and social thought leaders: For a transformation in food systems to occur, we need strong leadership, both intellectual and political, to escalate the issue to the highest levels. Growing support from world leaders is welcome, but this leadership needs to catalyze ambitious and transformative actions across private and public stakeholders, acknowledging pluralistic values and approaches. Building on an effective science-policy nexus, there is an opportunity to capacitate youth and catalyze action in areas that require social change such as diets and social norms.

> "To achieve the SDGs and to succeed in business, 'business as usual' is no longer an option. **We need to 'Re-imagine' our approaches, including new solutions, innovative partnerships, and strategies** to deliver these actions at scale within this decade."
>
> *—Sunny Verghese, Co-Founder and Group CEO, Olam*

Annex 1. Approach and methods

Transforming food systems under a changing climate is an initiative led by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) together with a wide range of partners that aims to realize a transformation in food systems by mobilizing knowledge and catalyzing action. The initiative brings together leaders in science, business, farming, policy and grassroots organizations to identify pathways for transformation.

To date, the process for this initiative has involved six main elements:

1. In 2019, five work packages were developed on key areas of food systems that have the potential to redefine the way the food systems function and which need to advance within the next decade. Each work package was commissioned to produce a report. The five reports, as well as briefing versions of each, are accessible below and through the initiative website, www.transformingfoodsystems.com:
   - Future technologies and food systems innovation for accelerating progress towards the Sustainable Development Goals
   - Adaptation and development pathways for different types of farmers
   - Transforming food systems under climate change: local to global policy as a catalyst for change
   - Financing the transformation of food systems under a changing climate
   - What is the role of changing diets in the transformation of the global food system?
2. A Panel of Experts was then formed. This globally representative group of leaders in business, development and science was tasked with preparing the final "Vision and Action Report"—this report—drawing on the reports of the five work packages above.
3. At the same time, an Advisory Group was formed to provide strategic advice on the positioning of the initiative, facilitate connections with other relevant initiatives, and support communication and dissemination of the Vision and Action Report.
4. A consultative process involving events in Bonn, Cape Town, Katowice, Oxford, Rome, Zurich, Bali and Madrid was carried out to solicit input to the initiative and feedback on drafts of the Vision and Action Report.
5. The Vision and Action Report on transforming food systems under climate change was published.
6. Alongside these steps, a major communications campaign has been carried out to raise awareness of the initiative, engage a variety of stakeholder groups, and share outcomes.

Endnotes

1. Béné C, Oosterveer P, Lamotte L, Brouwer ID, de Haan S, Prager SD, Talsma EF, Khoury CK. 2019. When Food Systems Meet Sustainability—Current Narratives and Implications for Actions. *World Dev*. 113:116–130. Available at: https://doi.org/10.1016/j.worlddev.2018.08.011
2. IPCC. 2019. *An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Summary for Policymakers*. Geneva: Intergovernmental Panel on Climate Change (IPCC). Available at: https://www.ipcc.ch/site/assets/uploads/sites/4/2019/12/02_Summary-for-Policymakers_SPM.pdf
3. EAT-LANCET Commission. 2019. *Healthy Diets from Sustainable Food Systems. Summary Report of the EAT-Lancet Commission*. Available at: https://eatforum.org/content/uploads/2019/07/EAT-Lancet_Commission_Summary_Report.pdf
4. SBTi. 2016. *Science-based GHG emissions targets for agriculture and forestry commodities*. The University of Aberdeen, PBL Netherlands Environmental Assessment Agency and Ecofys. Available at: https://www.pbl.nl/sites/default/files/downloads/pbl-2016-science-based-greenhouse-gas-emissions-targets-for-agriculture-and-forestry-commodities-2856.pdf
5. FAO. 2018. *Zero-deforestation commitments. A new avenue towards enhanced forest governance?* Rome: FAO. Available at: http://www.fao.org/3/i9927en/I9927EN.pdf
6. Our World in Data, 2018. Global greenhouse gas emissions scenarios. https://ourworldindata.org/uploads/2018/04/Greenhouse-gas-emission-scenarios-01.png
7. FAOSTAT. Prevalence of undernutrition. Available at: http://www.fao.org/faostat/en/#data/FS
8. FAO, IFAD, UNICEF, WFP and WHO. 2018. *The State of Food Security and Nutrition in the World 2018. Building climate resilience for food security and nutrition*. Rome, FAO. Available at: http://www.fao.org/3/i9553en/i9553en.pdf
9. WHO. Global Nutrition Report. Available at: https://www.who.int/nutrition/globalnutritionreport/en/
10. Castañeda A, Doan D, Newhouse D, Nguyen MC, Uematsu H, Azevedo JP. 2016. *Who are the poor in the developing world*. Policy Research Working Paper 7844. World Bank. Available at: http://documents.worldbank.org/curated/en/187011475416542282/pdf/WPS7844.pdf
11. Thornton PK, Loboguerrero AM, Campbell BM, Kavikumar KS, Mercado L, Shackleton S. 2019. *Rural livelihoods, food security and rural transformation under climate change. Background Paper Global Commission on Adaptation*. Rotterdam and Washington, DC: Global Commission on Adaptation. Available at: https://cdn.gca.org/assets/2019-09/RuralLivelihoodsFoodSecurityRuralTransformation_V2.pdf
12. FAO. 2017. The future of food and agriculture – Trends and challenges. Rome: FAO. Available at: http://www.fao.org/3/a-i6583e.pdf
13. Rao N, Elaine T. Lawson ET, Raditloaneng WN, Solomon D, Angula MN. 2019. Gendered vulnerabilities to climate change: insights from the semi-arid regions of Africa and Asia. *Climate and Development* 11(1):14–26. Available at: https://www.tandfonline.com/doi/full/10.1080/17565529.2017.1372266
14. Khatri-Chhetri A, Regmi PP, Chanana N., et al. 2020. Potential of climate-smart agriculture in reducing women farmers' drudgery in high climatic risk areas. *Climatic Change* 158:29. Available at: https://doi.org/10.1007/s10584-018-2350-8
15. Roser M, Ortiz-Ospina E. 2020. *Global Extreme Poverty*. Our World in Data. Published online at OurWorldInData.org. Available at: https://ourworldindata.org/extreme-poverty
16. Davis KF, Yu K, Herrero M, Havlik P, Carr JA, D'Odorico P, Odorico PD. 2015. Historical trade-offs of livestock's environmental impacts. *Environmental Research Letters* 10:125013. Available at: https://iopscience.iop.org/article/10.1088/1748-9326/10/12/125013/meta
17. Campbell BM, Hansen J, Rioux J, Stirling C, Twomlow S, Wollenberg E. 2018. Urgent action to combat climate change and its impacts (SDG 13): transforming agriculture and food systems. *Current Opinion in Environmental Sustainability* 34:13-20. Available at: https://doi.org/10.1016/j.cosust.2018.06.005
18. Columbia Water Center. 2019. Achieving Sustainable Water, Energy and Agriculture in Gujarat, India. Available at: http://water.columbia.edu/research-themes/water-food-energy-nexus/water-agriculture-livelihood-security-in-india/gujarat-india/
19. Voiland A. 2016. *Methane Matters. Scientists Work to Quantify the Effects of a Potent Greenhouse Gas*. Earth Observatory. Available at: https://earthobservatory.nasa.gov/features/MethaneMatters
20. Smith MR, Myers SS. 2018. Impact of anthropogenic CO_2 emissions on global human nutrition. *Nature Climate Change* 8:834–839. Available at: https://environment.harvard.edu/sites/default/files/smith_2018_impact_of_anthropogenic_co2_emissions_on_global_human_nutrition.pdf
21. Porter JR, Xie L, Challinor AJ, Cochrane K, Howden SM, Iqbal MM, Lobell DB, Travasso MI. 2014. Food security and food production systems. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma, B Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL, eds. Climate Change 2014: *Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 485-533. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap7_FINAL.pdf
22. Thornton PK. Jones PG, Ericksen PJ, Challinor AJ. 2011. Agriculture and Food Systems in Sub-Saharan Africa in a 4°C+ World. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 369(1934):117–136. Available at: https://doi.org/10.1098/rsta.2010.0246
23. FAO. 2018. *The State of World Fisheries and Aquaculture 2018—Meeting the sustainable development goals*. Rome: FAO. Available at: http://www.fao.org/3/I9540EN/i9540en.pdf
24. CRED. 2019. CRED report on Natural Disasters 2018. Brussels: Centre for Research on the Epidemiology of Disasters. Available at: https://www.cred.be/natural-disasters-2018
25. Vogel E, Donat MG, Alexander LV, Meinshausen M, Ray DK, Karoly D, Meinshausen N, Frieler K. 2019. The effects of climate extremes on global agricultural yields. *Environmental Research Letters* 14(5):054010. Available at: https://iopscience.iop.org/article/10.1088/1748-9326/ab154b
26. Brown O. 2008. Migration and Climate Change. IOM Migration Research Series, No. 31. Geneva: International Organization for Migration. Available at: https://www.iom.cz/files/Migration_and_Climate_Change_-_IOM_Migration_Research_Series_No_31.pdf

27. Maystadt JF, Ecker O. 2014. Extreme Weather and Civil War: Does Drought Fuel Conflict in Somalia through Livestock Price Shocks? *American Journal of Agricultural Economics* 96(4):1157–1182. Available at: https://doi.org/10.1093/ajae/aau010

28. Yale University. *Yale Global Forest Atlas, Industrial Agriculture*. New Haven: Yale University. Available at: https://globalforestatlas.yale.edu/land-use/industrial-agriculture

29. Campbell BM, Beare DJ, Bennett EM, Hall-Spencer JM, Ingram JSI, Jaramillo F, Ortiz R, Ramankutty N, Sayer JA, Shindell D. 2017. Agriculture production as a major driver of the Earth system exceeding planetary boundaries. *Ecology and Society* 22(4):8. Available at: https://doi.org/10.5751/ES-09595-220408

30. IPBES. 2019. Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES Secretariat, 2019). Available at: https://doi.org/10.1111/padr.12283

31. Neufeldt H, Jahn M, Campbell BM. Beddington JR, DeClerck F, De Pinto A, Gulledge J, Hellin J, Herrero M, Jarvis A, LeZaks D, Meinke H, Rosenstock T, Scholes M, Scholes R, Vermeulen S, Wollenberg E, Zougmoré R. 2013. Beyond climate-smart agriculture: toward safe operating spaces for global food systems. *Agric & Food Secur* 2:12. Available at: https://doi.org/10.1186/2048-7010-2-12

32. FAO. 2018. *Sustainable food systems. Concept and framework*. Rome: FAO. Available at: http://www.fao.org/3/ca2079en/CA2079EN.pdf

33. FAO, IFAD, UNICEF, WFP and WHO. 2019. *The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns*. Rome, FAO. Available at: http://www.fao.org/3/ca5162en/ca5162en.pdf

34. Wong F, Vos A, Pyburn R, Newton J. 2019. *Implementing gender transformative approaches in agriculture*. A discussion paper for the European Commission. CGIAR Collaborative Platform on Gender Research. Available at: https://42q77i2rw7d03mfrrd11pvzz-wpengine.netdna-ssl.com/wp-content/uploads/2019/07/Gender-Transformative-Approaches-in-Agriculture_DP-ONLY_-no-annexes.June-2019.pdf

35. UN Environment. 2019. *Collaborative Framework for Food Systems Transformation*. Nairobi: United Nations Environment Programme. Available at: https://www.oneplanetnetwork.org/sites/default/files/un-e_collaborative_framework_for_food_systems_transformation_final.pdf

36. Vermeulen SJ, Dinesh D, Howden SM, Cramer L, Thornton PK. 2018. Transformation in Practice: A Review of Empirical Cases of Transformational Adaptation in Agriculture Under Climate Change. Front Sustain Food Syst 2:65. Available at: https://www.frontiersin.org/articles/10.3389/fsufs.2018.00065/full

37. WBCSD. 2018. *Food Systems Modeling. Mexico Case Study*. World Business Council for Sustainable Development, Available at: https://docs.wbcsd.org/2018/10/Food_Systems_Modeling_Case_Study.pdf

38. IFPRI. 2019. *Policy transformation for achieving the SDGs: Can translational research help?* Washington DC: International Food Policy Research Institute. Available at: https://www.ifpri.org/blog/policy-transformation-achieving-sdgs-can-translational-research-help

39. Bapna M, Brandon C, Chan C, Patwardhan A, Dickson B. 2019. Adapt Now: *A Global Call For Leadership On Climate Resilience*. Rotterdam: Global Center on Adaptation. Available at: https://cdn.gca.org/assets/2019-09/GlobalCommission_Report_FINAL.pdf

40. Thornton PK, Kristjanson P, Förch W, Barahona C, Cramer L, Pradhan S. 2018. Is agricultural adaptation to global change in lower-income countries on track to meet the future production challenge? *Global Environmental Change* 52:37–48. Available at: https://doi.org/10.1016/j.gloenvcha.2018.06.003

41. Lennox E. 2015. Double Exposure to Climate Change and Globalization in a Peruvian Highland Community. *Society & Natural Resources* 28:781–796. Available at: https://doi.org/10.1080/08941920.2015.1024364

42. Maldonado J, Shearer C, Bronen R, Peterson K, Lazrus H. 2013. The impact of climate change on tribal communities in the US: displacement, relocation, and human rights. *Climatic Change* 120: 601–614. Available at: http://wordpress.ei.columbia.edu/climate-adaptation/files/2017/10/Maldonado-et-al-2011-Tribal-resettlement-US_ClimaticChange.pdf

43. Katz M. 2003. Staying afloat. How federal recognition as a Native American will save the residents of Isle de Jean Charles, Louisiana. *Loyola Journal of Public Interest Law* 4:1–26. Available at: https://heinonline.org/HOL/Page?handle=hein.journals/loyjpubil4&id=5&collection=journals&index=

44. Vermeulen S, Park T, Khoury CK, Mockshell J, Béné C, Thi HT, Heard B, Wilson B. 2019. *Changing diets and transforming food systems*. CCAFS Working Paper no. 282. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available at: https://cgspace.cgiar.org/bitstream/handle/10568/103987/Changing%20diets%20and%20transforming%20food%20systems%20WP%20282_repaired.pdf

45. United Nations Climate Change. 2019. *MAX Burgers: Creating the World's First "Climate Positive" Menu Sweden, Norway, Denmark, Poland*. Bonn: United Nations Climate Change. Available at: https://unfccc.int/climate-action/momentum-for-change/climate-neutral-now/max-burgers

46. See Annex 1 for a description of the approach and methods.

47. Stringer LC, Fraser EDG, Harris D, Lyon C, Pereira L, Ward CFM, Simelton E. 2019. Adaptation and development pathways for different types of farmers. *Environmental Science & Policy* 104: 174–189. Available at: https://www.sciencedirect.com/science/article/pii/S1462901119305209

48. Own calculations based on an incomplete factorial classification using six variables from global data sets: farm size (small/medium/large), travel time to market (high/low), agricultural suitability (high/low), climate hazard (high/low), access to credit (high/low), higher-tech economies (yes/no).

49. Bajželj B, Richards KS, Allwood JM, Smith P, Dennis JS, Curmi E, Gilligan CA. 2014. Importance of food-demand management for climate mitigation. *Nature Climate Change* 4:924–929. Available at: https://www.nature.com/articles/nclimate2353

50. Gernaat DEHJ, Calvin K, Lucas PL, Luderer G, Otto SAC, Rao S, Strefler J, van Vuuren DP. 2015. Understanding the contribution of non-carbon dioxide gases in deep mitigation scenarios. *Global Environmental Change* 33:142–153, Available at: https://doi.org/10.1016/j.gloenvcha.2015.04.010

51. Rogelj J, Shindell D, Jiang K, Fifita S, Forster P, Ginzburg V, Handa C, Kheshgi H, Kobayashi S, Kriegler E, Mundaca L, Séférian R, Vilariño MV. 2018. Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, and Waterfield T, eds. *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter2_Low_Res.pdf

52. Frank S, Beach R, Havlík P, Valin H, Herrero M, Mosnier A, Hasegawa T, Creason J, Ragnauth S, Obersteiner M. 2018. Structural change as a key component for agricultural non-CO2 mitigation efforts. *Nature Communications* 9(1060). Available at: https://www.nature.com/articles/s41467-018-03489-1

53. Pendrill F, Persson UM, Godar J, Kastner T, Moran D, Schmidt S, Wood R. 2019. Agricultural and forestry trade drives large share of tropical deforestation emissions. *Global Environmental Change* 56:1–10. Available at: https://www.sciencedirect.com/science/article/pii/S0959378018314365?via%3Dihub

54. Searchinger T, Waite R, Hanson C, Ranganathan J, Matthews E. 2019. *Creating a Sustainable Food Future. A Menu of Solutions to Feed Nearly 10 Billion People by 2050 (Final Report)*. World Resources Institute. Available at: https://www.wri.org/publication/creating-sustainable-food-future-final-report

55. Vermeulen SJ, Campbell BM, Ingram JS. 2012. Climate change and food systems. Annual Review of Environment and Resources 37:195–222. Available at: https://www.annualreviews.org/doi/abs/10.1146/annurev-environ-020411-130608

56. Gibbs HK, Salmon JM. 2015. Mapping the world's degraded lands. *Applied Geography* 57:12–21. Available at: https://doi.org/10.1016/j.apgeog.2014.11.024

57. Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O. 2007. Agriculture. In Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, eds. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg3-chapter8-1.pdf

58. Springmann M, Clark M, Mason-D'Croz D, Wiebe K, Bodirsky BL, Lassaletta L, de Vries W, Vermeulen S, Herrero M, Carlson K, Jonell M, Troell M, DeClerck F, Gordon L, Zurayk R, Scarborough P, Rayner M, Loken B, Fanzo J, Godfray HC, Tilman D, Rockström J, Willett W. 2018. *Options for keeping the food system within environmental limits*. Nature 562:519–525. Available at: https://doi.org/10.1038/s41586-018-0594-0

59. Howden SM, Soussana JF, Tubiello FN, Chhetri N, Dunlop M, Meinke H. 2007. Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences* 104 (50):19691–19696. Available at: https://www.pnas.org/content/104/50/19691

60. With vulnerability mapped as those places with high exposure to climate change hazards (e.g. related to water), high sensitivity owing to the importance of agriculture in the region, and low coping capacity (i.e. areas where child under-nutrition is already challenging).

61. The multi-dimensional poverty index is constructed from ten indicators across three core dimensions: health, education and living standards.

62. Lobell DB, Cassman KG, Field CB. 2009. Crop Yield Gaps: Their Importance, Magnitudes, and Causes. *Annual Review of Environment and Resources* 34:179–204. Available at: https://www.annualreviews.org/doi/10.1146/annurev.environ.041008.093740

63. Mayberry D, Ash A, Prestwidge D, Godde CM, Henderson B, Duncan A, Blummel M, Reddy R, Herrero M. 2017. Yield gap analyses to estimate attainable bovine milk yields and evaluate options to increase production in Ethiopia and India. *Agricultural Systems* 155:43–51. Available at: https://www.sciencedirect.com/science/article/pii/S0308521X16304206

64. Ouédraogo, M., Zougmoré, R., Moussa, Samuel AS, Partey T,Thornton PK, Kristjanson P, Ndèye Y. Ndour B, Somé L, Naab J, Boureima M, Diakité L, Quiros C. 2017. *Reg Environ Change* 17:437–449. Available at: https://doi.org/10.1007/s10113-016-1029-9

65. Harris D. 2019. Intensification Benefit Index: how much can rural households benefit from agricultural intensification? *Experimental Agriculture* 55:(2)273–287. Available at: https://doi.org/10.1017/S0014479718000042

66. Slavchevska V, Kaaria S, Taivalmaa SL. 2016. *Feminization of agriculture in the context of rural transformations: What is the evidence?* Washington, DC: World Bank Group. Available at: https://doi.org/10.1596/25099

67. Allan T, Bromwich B, Keulertz M, Colman A, eds. 2019. The Oxford Handbook of Food, Water and Society. Oxford University Press. Available at: https://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780190669799.001.0001/oxfordhb-9780190669799

68. White B. 2015. Generational dynamics in agriculture: reflections on rural youth and farming futures. *Cahiers Agricultures* 24(6):330–334. Available at: https://www.cahiersagricultures.fr/articles/cagri/pdf/2015/06/cagri2015246p330.pdf

69. Newton P, Agrawal A, Wollenberg E. 2013. Enhancing the sustainability of commodity supply chains in tropical forest and agricultural landscapes. *Global Environmental Change* 23(6):1761–1772. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0959378013001398?via%3Dihub

70. WWF. 2015. *WWF Living Forests Report, Saving Forests at Risk*. WWF. Available at: http://awsassets.panda.org/downloads/lfr_chapter_5_executive_summary_final.pdf

71. ZDWG. 2017. A Pathway to Zero Deforestation in the Brazilian Amazon. Zero Deforestation Working Group. Available at: https://ipam.org.br/wp-content/uploads/2017/11/A-Pathway-to-Zero-Deforestation-in-the-Brazilian-Amazon-full-report.pdf

72. Mafira T, Muluk S, Conway S. 2019. From Digging to Planting: A Sustainable Economic Transition for Berau, East Kalimantan. Climate Policy Initiative. Available at: https://climatepolicyinitiative.org/wp-content/uploads/2019/08/From-Digging-to-Planting.pdf

73. Refer to conventional small-scale (increasing market integration) in Table 1.

74. Fraval S, Hammond J, Lannerstad M, Oosting SJ, Sayula G, Teufel N, Silvestri S, Poole EJ, Herrero M, van Wijk MT. 2018. Livelihoods and food security in an urban linked, high potential region of Tanzania: Changes over a three year period. *Agricultural Systems* 160:87–95. Available at: https://doi.org/10.1016/j.agsy.2017.10.013

75. Tavenner K, Fraval S, Omondi I, Crane TA. 2018. Gendered reporting of household dynamics in the Kenyan dairy sector: trends and implications for low emissions dairy development. *Gender, Technology and Development* 22(1):1–19. Available at: https://www.tandfonline.com/doi/full/10.1080/09718524.2018.1449488

76. Schaer C, Kuruppu ND, eds. 2018. *Private-sector action in adaptation: Perspectives on the role of micro, small and medium size enterprises*. UNEP DTU Partnership. Available at: https://orbit.dtu.dk/en/publications/private-sector-action-in-adaptation-perspectives-on-the-role-of-m

77. Amsler K, Hein C, Klasek G. 2017. Youth Decision Making in Agricultural Climate Change Adaptations: Research findings from East Africa. CCAFS Info Note. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available at: https://ccafs.cgiar.org/fr/node/54446#.Xjq_3i97GjQ

78. Huyer S, Twyman J, Koningstein M, Ashby J, Vermeulen S. 2015. *Supporting women farmers in a changing climate: five policy lessons*. CCAFS Policy Brief no. 10. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available at: https://cgspace.cgiar.org/bitstream/handle/10568/68533/CCAFS%20PB10.pdf

79. Huyer S. 2016. Closing the Gender Gap in Agriculture. *Gender, Technology and Development* 20(2):105–116. Available at: https://www.tandfonline.com/doi/abs/10.1177/0971852416643872

80. Murray U, Gebremedhin Z, Brychkova G, Spillane C. 2016. Smallholder Farmers and Climate Smart Agriculture: Technology and Labor-productivity Constraints amongst Women Smallholders in Malawi. *Gender, Technology and Development* 20(2):117–148. Available at: https://www.tandfonline.com/doi/abs/10.1177/0971852416640639

81. Beuchelt TD, Badstue L. 2013. Gender, nutrition- and climate-smart food production: Opportunities and trade-offs. *Food Security* 5:709–721. Available at: https://link.springer.com/article/10.1007%2Fs12571-013-0290-8

82. Theis S, Lefore N, Meinzen-Dick R, Bryan E. 2018. What happens after technology adoption? Gendered aspects of small-scale irrigation technologies in Ethiopia, Ghana, and Tanzania. *Agric Hum Values* 35:671–684. Available at: https://doi.org/10.1007/s10460-018-9862-8

83. Ethiopian Agricultural Transformation Agency. Available at: http://www.ata.gov.et

84. Suri T, Jack W. 2016. The long-run poverty and gender impacts of mobile money. *Science* 354(6317):1288–1292. Available at: https://science.sciencemag.org/content/354/6317/1288

85. Ndiaye O. 2013. Is the success of M-Pesa empowering Kenyan rural women? *Feminist Africa* 18:156–161. Available at: http://www.agi.ac.za/sites/default/files/image_tool/images/429/feminist_africa_journals/archive/18/standpoints_is_the_success_of_m-pesa_empowering_kenyan_rural_women_.pdf

86. AgDevCo, with investments in 40 initiatives across Africa, link farmers to markets and in so doing create jobs, with a ratio of 1 job per 40 farmers linked. If Action 1.2 is achieved this would create 7.5 million jobs. But agricultural growth also drives demand for non-farm goods and services, Mellor et al. (2001) estimating that additions to employment in agriculturally stimulated non-farm sector will be some 60% higher than in agriculture. Thus we estimate 12 million non-agricultural jobs.

87. Mellor JW, Altaf Z, Salam A. 2001. Employment Multipliers from Agricultural Growth and Poverty Reduction. *The Pakistan Development Review*. 40:371–400. Available at: https://www.researchgate.net/publication/24046274_Employment_Multipliers_from_Agricultural_Growth_and_Poverty_Reduction

88. Davis B, Di Giuseppe S, Zezza A. 2017. Are African households (not) leaving agriculture? Patterns of households' income sources in rural Sub-Saharan Africa. *Food Policy* 67:153–174. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5384437/

89. Elias M, Mudege N, Lopez DE, Najjar D, Kandiwa V, Luis J, Yila J, Tegbaru A, Ibrahim G, Badstue L, Njuguna-Mungai E, Bentaibi A. 2018. Gendered aspirations and occupations among rural youth, in agriculture and beyond: A cross-regional perspective. *Journal of Gender, Agriculture and Food Security* 3(1):82–107. Available at: http://agrigender.net/views/gendered-aspirations-and-occupations-among-rural-youth-JGAFS-312018-4.php

90. Kosec K, Ghebru H, Holtemeyer B, Mueller V, Schmidt E. 2018. The Effect of Land Access on Youth Employment and Migration Decisions: Evidence from Rural Ethiopia. *American Journal of Agricultural Economics* 100:931–954. Available at: https://onlinelibrary.wiley.com/doi/full/10.1093/ajae/aax087

91. Afifi T, Milan A, Etzold B, Schraven B, Rademacher-Schulz C, Sakdapolrak P, Reif A, van der Geest K, Warner K. 2016. Human mobility in response to rainfall variability: opportunities for migration as a successful adaptation strategy in eight case studies. *Migration and Development* 5(2):254–274. Available at: https://www.tandfonline.com/doi/full/10.1080/21632324.2015.1022974

92. Cabral L, Sumberg J. 2017. *Youth, smart phones and tractors in Africa—a new agrarian class?* Institute of Development Studies. Available at: https://www.ids.ac.uk/opinions/youth-smart-phones-and-tractors-in-africa-a-new-agrarian-class/

93. Hello Tractor. 2018. *Impact Whitepaper.* Hello Tractor. Available at: https://www.hellotractor.com/wp-content/uploads/2018/09/IMPACT-WP.pdf

94. Partey ST, Dakorah AD, Zougmoré RB, Ouédraogo M, Nyasimi M, Nikoi GK, Huyer S. 2020. Gender and climate risk management: evidence of climate information use in Ghana. *Climatic Change* 158(1):61–75. Available at: https://doi.org/10.1007/s10584-018-2239-6

95. Diouf NS, Ouedraogo I, Zougmoré RB, Ouedraogo M, Partey S, Gumucio T. 2019. Factors influencing gendered access to climate information services for farming in Senegal. Gender, Technology and Development 23(2:)93–110. Available at: https://www.tandfonline.com/doi/full/10.1080/09718524.2019.1649790

96. IFRC. 2019. *The cost of doing nothing. The humanitarian price of climate change and how it can be avoided*. Geneva: International Federation of Red Cross and Red Crescent Societies. Available at: https://media.ifrc.org/ifrc/the-cost-of-doing-nothing/. This report from the International Federation of Red Cross and Red Crescent Societies estimates that 150 million people will need humanitarian aid each year by 2030 at a cost of about US$ 20 billion per year. Our target assumes we can build the resilience of two thirds of rural dwellers and remove them from humanitarian assistance.

97. OCHA. 2020. *Global Humanitarian Overview 2020*. Geneva: United Nations Office for the Coordination of Humanitarian Affairs. Available at: https://www.unocha.org/sites/unocha/files/GHO-2020_v9.1.pdf

98. FAO. 2019. Global report on food crises. Rome: FAO.

99. Brown S, Budimir M, Sneddon A, Lau D, Shakya P, Upadhyay S. 2019. *Gender Transformative Early Warning Systems: Experiences from Nepal* and Peru. Rugby, UK: Practical Action. Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/Gender%20Transformative%20Early%20Warning%20Systems.pdf

100. Cochran L, Tamiru Y. 2016. Ethiopia's Productive Safety Net Program: Power, Politics and Practice. *Journal of International Development* 28(5):649–665. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1002/jid.3234

101. African Risk Capacity. Available at: https://www.africanriskcapacity.org

102. Refer to "More likely to be digitally connected" and "More extensive farmers in riskier environments" columns in Table 1.

103. Bageant ER, Barrett CB. 2017. Are There Gender Differences in Demand for Index-Based Livestock Insurance?, *The Journal of Development Studies* 53(6):932–952. Available at: https://www.tandfonline.com/doi/full/10.1080/00220388.2016.1214717

104. Akter S, Krupnik TJ, Rossi FJ, Khanam F. 2016. The influence of gender and product design on farmers' preferences for weather-indexed crop insurance. *Glob Environ Chang* 38:217–229. Available at: https://www.ncbi.nlm.nih.gov/pubmed/27212804

105. Clarke DJ, Kumar N. 2016. Microinsurance Decisions: Gendered Evidence from Rural Bangladesh. *Gender, Technology and Development* 20(2):218–241. Available at: https://www.tandfonline.com/doi/abs/10.1177/0971852416639784

106. Greatrex H, Hansen JW, Garvin S, Diro R, Blakeley S, Le Guen M, Rao KN, Osgood DE. 2015. *Scaling up index insurance for smallholder farmers: Recent evidence and insights*. CCAFS Report No. 14 Wageningen: CGIAR Research Program on Climate Change, Agriculture and Food Security. Available at: https://cgspace.cgiar.org/bitstream/handle/10568/53101/CCAFS_Report14.pdf

107. Garnett T, Mathewson S, Angelides P, Borthwick F. 2015. *Policies and actions to shift eating patterns: What works?* Oxford and London, UK: Food Climate Research Network (FCRN) and Chatham House, The Royal Institute of International Affairs. Available at: https://www.fcrn.org.uk/sites/default/files/fcrn_chatham_house_0.pdf

108. Nelson ME, Hamm MW, Hu FB, Abrams SA, Griffin TS. 2016. Alignment of Healthy Dietary Patterns and Environmental Sustainability: A Systematic Review. *Advances in Nutrition*, 7(6):1005–1025. Available at: https://doi.org/10.3945/an.116.012567

109. Poore J, Nemecek T. 2018. Reducing food's environmental impacts through producers and consumers. Science 360(6392):987–992. Available at: https://science.sciencemag.org/content/sci/360/6392/987.full.pdf

110. Stehfest E, Berg MVD, Woltjer G, Msangi S, Westhoek H. 2013. Options to reduce the environmental effects of livestock production: comparison of two economic models. *Agricultural Systems* 114:38–53. Available at: http://dx.doi.org/10.1016/j.agsy.2012.07.002

111 FOLU. 2019. *Growing Better: Ten Critical Transitions to Transform Food and Land Use. Food and Land Use Coalition*. Available at: https://www.foodandlandusecoalition.org/wp-content/uploads/2019/09/FOLU-GrowingBetter-GlobalReport.pdf

112. Lucas T, Horton R. 2019. The 21st-century great food transformation. *The Lancet* 393(10170): 386–387. Available at: https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(18)33179-9/fulltext

113. University of Leeds, ARUP, C40 Cities. 2019. *Addressing food-related consumption-based emission in C40 cities*. Available at: https://drive.google.com/file/d/1-_U6YflETGE-2hP5Qau3SLBlnvzsPdBw/view

114. Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G. 2013. *Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities*. Rome: Food and Agriculture Organization of the United Nations (FAO). Available at: http://www.fao.org/3/a-i3437e.pdf

115. FAO, ITPS. 2018. *Global agriculture towards 2050*. High-Level Export Forum. Rome: Food and Agriculture Organization of the United Nations (FAO). 162 pp. Available at: http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf

116. Springmann M, Godfray HCJ, Rayner M, Scarborough P. 2016. Analysis and valuation of the health and climate change cobenefits of dietary change. *PNAS* 113(15):4146–4151. Available at: https://www.pnas.org/content/113/15/4146

117. Meltzer MI. 1995. Livestock in africa: The economics of ownership and production, and the potential for improvement. *Agric Hum Values* 12: 4018. Available at: https://doi.org/10.1007/BF02217292

118. Brandt P, Herold M, Rufino M. 2018. The contribution of sectoral climate change mitigation options to national targets: A quantitative assessment of dairy production in Kenya. *Environmental Research Letters* 13(3). Available at: https://iopscience.iop.org/article/10.1088/1748-9326/aaac84

119. Our World in Data. 2019. *Meat supply per person* 2013. Available at: https://ourworldindata.org/grapher/meat-supply-per-person

120. Our World in Data. 2019. *Per capita milk consumption 2013*. Available at: https://ourworldindata.org/grapher/per-capita-milk-consumption

121. C40 Cities. Available at: https://www.c40.org/cities

122. Sexton AE, Garnett T, Lorimer J. 2019. Framing the future of food: The contested promises of alternative proteins. *Nature and Space* 2(1):47–72. Available at: https://doi.org/10.1177/2514848619827009

123. Byrd E. 2018. *Cellular Agriculture. A global food security solution*. The Good Food Institute (GFI). Available at: http://www.gfi.org/cellular-agriculture-a-global-food-security

124. O'Neil K. 2017. *Is Protein a Key to Feeding Ten Billion?* Rockefeller Foundation blog. Available at: https://www.rockefellerfoundation.org/blog/protein-key-feeding-ten-billion/

125. Meatless Monday Global. Available at: http://www.meatlessmonday.com

126. PSU. 2017. *Meatless Mondays: Do They Really Help?*. Mathematics for Sustainability blog, October 8, 2017. Pennsylvania State University. Available at: https://sites.psu.edu/math033fa17/2017/10/08/meatless-mondays-do-they-really-help/

127. Guo X, Broeze J, Groot J, Axmann H, Vollebregt M. 2019. *A global hotspot analysis on food loss & waste and associated greenhouse gas emissions*. CCAFS Working Paper no. 290. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available at: https://cgspace.cgiar.org/bitstream/handle/10568/106249/WP290.pdf

128. Champions 12.3. 2017. *Road map to achieving SDG target 12,3*. Available at: https://champions123.org/wp-content/uploads/2017/09/champions-123-roadmap-to-achieving-sdg-target-123.pdf

129. FLW. 2020. *Food Loss + Waste Protocol*. Available at: https://www.flwprotocol.org

130. Lipinski B, Hanson C, Lomax J, Kitinoja L, Waite R, Searchinger T. 2013. *Reducing Food Loss and Waste. Working Paper, Installment 2 of Creating a Sustainable Food Future*. Washington, DC: World Resources Institute. Available at: https://pdf.wri.org/reducing_food_loss_and_waste.pdf

131. Gromko D, Abdurasalova G. 2019. *Climate change mitigation and food loss and waste reduction: Exploring the business case*. CCAFS Report No. 18. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available at: https://cgspace.cgiar.org/bitstream/handle/10568/100165/CCAFS%20R18.pdf

132. Hanson C, Mitchell P. 2017. *The business case for reducing Food Loss and Waste*. Champion 12.3 Available at: https://www.wrap.org.uk/sites/files/wrap/Report_The%20Business%20Case%20for%20Reducing%20Food%20Loss%20and%20Waste.pdf

133. BSDC. 2016. *Valuing the SDG prize in food and agriculture unlocking business opportunities to accelerate sustainable and inclusive growth*. London: Business and Sustainable Development Commission. Available at: http://s3.amazonaws.com/aws-bsdc/Valuing-SDG-Food-Ag-Prize-Paper.pdf

134. Fisher DR. 2019. The broader importance of #FridaysForFuture. *Nat. Clim. Chang.* 9:430–431. Available at: https://doi.org/10.1038/s41558-019-0484-y

135. FOLU. 2019. *Growing Better: Ten Critical Transitions to Transform Food and Land Use. Summary Report*. Available at: https://www.foodandlandusecoalition.org/wp-content/uploads/2019/09/FOLU-GrowingBetter-GlobalReport-SummaryReport.pdf

136. US$300 billion is the total amount of market price support in agriculture which comes from the 16 countries from the OECD that present the highest amount of market price support in agriculture for 2018 (OECD data: https://data.oecd.org/). Market price supports are highly distortionary as they restrict imports or exports.

137. Sub-Saharan Countries have the lowest average score, with 24 countries below that average.

138. These 49 countries are the ones that present an ND-GAIN Index (readiness variable) below 0.3.

139. Millan A, Limketkai B, Guarnaschelli S. 2019. *Financing the Transformation of Food Systems Under a Changing Climate*. CCAFS Report. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available at: https://cgspace.cgiar.org/bitstream/handle/10568/101132/CCAFS%20KOIS%20Financing%20the%20Transformation%20of%20Food%20Systems%20Under%20a%20Changing%20Climate.pdf

140. Howard PH. 2016. *Concentration and Power in the Food System. Who Controls What We Eat?* Bloomsbury Academic 3. Available at: https://www.bloomsbury.com/us/concentration-and-power-in-the-food-system-9781472581143/

141. FAO, IFAD, WFP. 2015. *Developing the knowledge, skills and talent of youth to further food security and nutrition*. Rome: FAO, IFAD, WFP. Available at: http://www.fao.org/3/a-i5024e.pdf

142. Bonny S. 2017. Corporate concentration and technological change in the global seed industry. *Sustainability*, 9. Available at: https://doi.org/10.3390/su9091632

143. Wiebe K, Zurek M, Lord S, Brzezina N, Gabrielyan G, Libertini J, Loch A, Thapa-Parajuli R, Vervoort J, Westhoek H. 2018. Scenario Development and Foresight Analysis: Exploring Options to Inform Choices. *Annual Review of Environment and Resources* 43(1):545–570. Available at: https://www.annualreviews.org/action/showCitFormats?doi=10.1146%2Fannurev-environ-102017-030109

144. WBG. 2016. *Just-in-time and Peer Learning in Climate Change*. Washington DC: World Bank Group. Available at: https://olc.worldbank.org/content/just-time-and-peer-learning-climate-change

145. UNDP. 2017. *Peer To Peer (P2p) Learning: An Alternative Development Approach for South-South Cooperation*. New York: United Nations Development Programme. Available at: https://www.undp.org/content/dam/undp/library/capacity-development/English/Singapore%20Centre/P2P_Learning-SSC_Nov2017.pdf

146. Notre Dame Global Adaptation Initiative. University of Notre Dame. Available at: https://gain.nd.edu/our-work/country-index/

147. OECD. 2019. Market Price Support estimates. Available at: https://www.oecd.org/agriculture/topics/agricultural-policy-monitoring-and-evaluation/

148. Brown M, Carr E, Grace K, Wiebe K, Funk C, Attavanich W, Backlund P, Buja L. 2017. Do markets and trade help or hurt the global food system adapt to climate change?. Food Policy. 68:154–159. Available at: https://www.researchgate.net/publication/313867394_Do_markets_and_trade_help_or_hurt_the_global_food_system_adapt_to_climate_change

149. Barclay E, Resnick B. 2019. How big was the global climate strike? 4 million people, activists estimate. Vox. Available at: https://www.vox.com/energy-and-environment/2019/9/20/20876143/climate-strike-2019-september-20-crowd-estimate

150. Williamson K, Satre-Meloy A, Velasco K, Green K. 2018. *Climate Change Needs Behavior Change: Making the Case For Behavioral Solutions to Reduce Global Warming.* Arlington, VA: Rare. Available at: https://rare.org/wp-content/uploads/2019/02/2018-CCNBC-Report.pdf

151. Dentoni D, Waddell S, Waddock S. 2017. Pathways of transformation in global food and agricultural systems: implications from a large systems change theory perspective. *Current Opinion in Environmental Sustainability* 29:8–13. Available at: https://www.researchgate.net/publication/321634856_Pathways_of_transformation_in_global_food_and_agricultural_systems_implications_from_a_large_systems_change_theory_perspective

152. Blay-Palmer A, Sonnino R, Custot J. 2016. A food politics of the possible? Growing sustainable food systems through networks of knowledge. *Agric Hum Values* 33:27–43. Available at: https://doi.org/10.1007/s10460-015-9592-0

153. Sage C. 2014. The transition movement and food sovereignty: From local resilience to global engagement in food system transformation. *Journal of Consumer Culture* 14(2):254–275. Available at: https://doi.org/10.1177/1469540514526281

154. Hinrichs CC. 2014. Transitions to sustainability: a change in thinking about food systems change? *Agric Hum Values* 31:143–155. Available at: https://doi.org/10.1007/s10460-014-9479-5

155. Kennedy EH, Parkins JR, Johnston J. 2018. Food activists, consumer strategies, and the democratic imagination: Insights from eat-local movements. *Journal of Consumer Culture* 18(1):149–168. Available at: https://doi.org/10.1177/1469540516659125

156. Andrée P, Clark J, Levkoe C, Lowitt K, eds. 2019. Civil society and social movements in food system governance. Routledge. Available at: https://doi.org/10.4324/9780429503597

157. Beintema N, Stads GJ, Fuglie K, Heisey P. 2012. *ASTI Global Assessment of Agricultural R&D Spending: Developing Countries Accelerate Investment*. International Food Policy Research Institute, Washington, DC; Agricultural Science and Technology Indicators, Rome; Global Forum on Agricultural Research, Rome. Available at: https://www.asti.cgiar.org/pdf/ASTI_global_assessment.pdf

158. Moosa I. 2018. Publish or Perish. Cheltenham: Edward Elgar Publishing.

159. Hall A, Dijkman J. 2019. *Public Agricultural Research in an Era of Transformation: The Challenge of Agri-Food System Innovation*. Rome and Canberra: CGIAR Independent Science and Partnership Council (ISPC) Secretariat and Commonwealth Scientific and Industrial Research Organisation (CSIRO). Available at: https://cas.cgiar.org/sites/default/files/pdf/syntetic-study-web-def.pdf

160. Wollenberg E, Richards M, Smith P, Havlík P, Obersteiner M, Tubiello FN, Herold M, Gerber P, Carter S, Reisinger A, van Vuuren D, Dickie A, Neufeldt H, Sander BO, Wassman R, Sommer R, Amonette JE, Falcucci A, Herrero M, Opio C, Roman-Cuesta R, Stehfest E, Westhoek H, Ortiz-Monasterio I, Sapkota T, Rufino MC, Thornton PK, Verchot L, West PC, Soussana JF, Baedeker T, Sadler M, Vermeulen S, Campbell BM. 2016. Reducing emissions from agriculture to meet the 2°C target. *Global Change Biology*. 22(12):3859–3864. Available at: https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.13340

161. Hristov AN, Oh J, Giallongo F, Frederick TW, Harper MT, Weeks HL, Branco AF, Moate PJ, Deighton MH, Williams RO, Kindermann M, Duval S. 2015. Enteric methane inhibitor. *Proceedings of the National Academy of Sciences* 112(34):10663–10668. Available at: https://doi.org/10.1073/pnas.1504124112

162. Herrero M, Thornton P, Mason-D'Croz D, Palmer J. 2019. *Transforming Food Systems Under a Changing Climate. Future technologies and food systems innovation for accelerating progress towards the SDGs: key messages*. CGIAR Transforming Food Systems Under a Changing Climate Initiative. Available at: https://cgspace.cgiar.org/bitstream/handle/10568/104050/Transformation%20Initiative%20Briefing%20-%20Tech%20A4%20for%20web_repaired.pdf

163. Otieno G, Lacasse H, Adokorach J, Mulumba JW, Recha JW, Reynolds TW, Fadda C. 2018. *Social Seed Networks for Climate Change Adaptation in Uganda: Strategies to Improve Access to Genetic Diversity and Information*. CCAFS Info Note. Wageningen, Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available at: https://cgspace.cgiar.org/bitstream/handle/10568/93207/Uganda%20%20info%20note%20_June.pdf

Photo credits

Cover: P. Vishwanathan (CCAFS)
Pg. 4: L. Sebastian (CCAFS)
Pg. 8: CCAFS Southeast Asia
Pg. 12: N. Palmer (CIAT)
Pg. 15: S. Samuel (CCAFS)
Pg. 16: J.L.Urrea (CCAFS)
Pg. 20: M. Koningstein (CIAT)
Pg. 25: L. Sebastian (CCAFS)
Pg. 28: K. Trautmann (CCAFS)
Pg. 31: P. Casier (CGIAR)
Pg. 37: N. Palmer (CIAT)
Pg. 44: A. Manik (CGIAR)
Pg. 45: P. Casier (CGIAR)
Pg. 46: G. Smith (CIAT)
Pg. 51: M. Yousuf Tushar (CGIAR)
Pg. 53: K. Trautmann (CCAFS)
Pg. 57: C. Schubert (CCAFS)

Transforming Food Systems Under a Changing Climate is an initiative led by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) together with a wide range of partners that aims to realize a transformation in food systems by mobilizing knowledge and catalyzing action.

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is a collaboration among CGIAR Centers and Research Programs, led by the International Center for Tropical Agriculture (CIAT), part of the Alliance of Bioversity International and CIAT.

CCAFS is carried out with support from the CGIAR Trust Fund and through bilateral funding agreements. For details please visit https://ccafs.cgiar.org/donors. The views expressed in this document cannot be taken to reflect the official opinions of these organizations.