Transforming Food Systems in Africa under Climate Change Pressure: Role of Climate-Smart Agriculture

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Abstract: Low-income producers and consumers of food in Africa are more vulnerable to climate change, owing to their comparatively limited ability to invest in more adapted institutions and technologies under increasing climatic risks. Therefore, the way we manage our food systems needs to be urgently changed if the goal is to achieve food security and sustainable development more quickly. This review paper analyzes the nexus "climate-smart agriculture-food systems-sustainable development" in order to draw sound ways that could allow rapid transformation of food systems in the context of climate change pressure. We followed an integrative review approach based on selected concrete example-experiences from ground-implemented projects across Africa (Ghana, Senegal, Mali, Burkina Faso, in West Africa, Ethiopia, Kenya, Rwanda, and Tanzania in East Africa). Mostly composed of examples from the Climate Change, Agriculture, and Food Security (CCAFS) Research Program of the CGIAR (former Consultative Group on International Agricultural Research) and its partners, these also included ground initiatives from non-CGIAR that could provide demonstrable conditions for a transformative agriculture and food systems. The lessons learnt from the ground implementation of climate-smart agriculture (CSA), in the African context, were instrumental to informing the actions areas of the food-system transformation framework suggested in this paper (reroute, de-risk, reduce, and realign). Selected CSA example-cases to inform these action areas included 24 initiatives across Africa, but with a focus on the following studies for an in-depth analysis: (1) the climate-smart village approach to generate knowledge on climate-smart agriculture (CSA) technologies and practices for their scaling, (2) the use of climate information services (CIS) to better manage climate variability and extremes, and (3) the science–policy interfacing to mainstream CSA into agricultural development policies and plans. The analysis of these examples showed that CSA can contribute driving a rapid change of food systems in Africa through: (1) the implementation of relevant climate-smart technologies and practices to reroute farming and rural livelihoods to new climate-resilient and low-emission trajectories; (2) the development and application of weather and climate information services (WCIS) that support de-risking of livelihoods, farms, and value chains in the face of increasing vagaries of weather and extreme events; (3) the use of climate-smart options that minimize waste of all the natural resources used for growing, processing, packaging, transporting, and marketing food, and therefore mitigating the carbon footprint attached to this food loss and waste; and (4) the realignment of policies and finance that facilitate action in the four proposed action areas through the identification of news ways to mobilize sustainable finance and create innovative financial mechanisms and delivery channels.

Keywords: food security; climate-smart technologies; weather and climate information services; loss and waste; sustainable finance; partnership; policies; Africa; CGIAR

1. Introduction

Achieving food security in the face of accelerating food demand, competition for depleting resources, and the failing ability of the environment to buffer increasing anthropogenic impacts is now widely seen as the foremost challenge of our time [1]. Current food systems are not on a sustainable trajectory that will enable us to reach the Sustainable Development Goals by 2030, and major failures are related to production and nutritional targets, inclusivity, and environmental footprint [2]. Moreover, climate change is one among a set of interconnected trends and risks facing agriculture and food systems [3]. According to Loboguerrero et al. [2], in relation to climate resilient food systems, we are falling short on taking the actions needed to limit global warming and we may be on track to a 3.1–3.7 °C warmer world, which is over the target of the Paris agreement and would be disastrous for food systems [4]. Indeed, Meyers et al. [5] reported that the world is now facing growing constraints in our capacity to appropriate new land, new water, or new fisheries to meet the growing food demands. In addition to the human-induced rapid transformation of Earth's natural systems, climate change, which is associated with increasing temperatures and more extreme rainfall, may alter relationships among crops, pests, pathogens, and weeds; and it exacerbates several trends including declines in pollinating insects, increasing water scarcity, increasing ground-level ozone concentrations, and fishery declines. Most future climate-change scenarios suggest that warming will generally depress yields for major staple crops (e.g., maize and wheat), with stronger yield losses expected in tropical regions [6]. Meta-analysis of impacts of climate change shows 70% of studies with declines in crop yields by 2030s, with half the studies having 10–50% declines [7].

Many food system actors are highly vulnerable: There will be at least 700 million small-scale agricultural producers in 2030, for example, and we are not on the right pathway to build their resilience to extreme events within a short period of time [8]. Also, according to FAO [9], climate change will cause 71 million food-insecure people, now due to COVID-19 pandemic potentially even more, with half from Sub-Sahara Africa, and with compounding issues such as loss of employment, income, nutrition, and well-being, degradation of lands and natural ecosystems, increase in conflicts.

It is expected that low-income producers and consumers of food in Africa will be more vulnerable to climate change because of their comparatively limited ability to invest in adaptive institutions and technologies under increasing climatic risks. Therefore, changing the way food systems are managed become even more pressing to achieve food security and sustainable development more quickly. By ratifying the 2015 Paris agreement, 188 countries and the EU have agreed that reconfigurations of food systems need to happen quickly, i.e., in the next ten years, if we are to achieve zero hunger, gender equality, and avoid dangerous climate change [2]. Numerous initiatives aiming to such reconfigurations are suggested by food systems actors, each of them trying to reroute onto new trajectories.

Of particular mention here is the Food system transformation initiative led by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) who worked with more than hundred partners to consider how to achieve this rapid, deep-seated change in food systems. A framework with four interlocking action areas for food systems reconfigurations has been proposed [10]: rerouting farming trajectories; increasing the resilience of all the agents involved in rapid change (reducing risks); minimizing the environmental footprint of food systems (from a climate change perspective, a focus on reducing emissions); and realigning the enablers of change. Through this framework, some synergies among food security, adaptation, and mitigation are feasible, in other words, climate-smart agriculture (CSA) has a key role to play for this food-system transformation in Africa. CSA is proposed as a solution to transform agricultural systems to support food security under the new realities of climate change. CSA refers to an agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes greenhouse gases (GHGs) (mitigation), and enhances achievement of national food security and development goals [11].

While the growth in strategies, policies, partnerships, and investments is positive and creates a favourable enabling environment for CSA, these need to be complemented with targeted implementation on the ground, sustainable financing, institutional coordination, and metrics to measure the efficacy of interventions [12]. Indeed, there is a need for a "safe operating space" for agricultural and food systems to set up conditions that demonstrably better meet human needs in the short and long term within foreseeable local and planetary limits and holds ourselves accountable for outcomes across temporal and spatial scales [13]. This will definitely help make agriculture and food systems climate-smart, i.e., when it can be shown that they bring us closer to safe operating spaces. CSA has been a powerful concept to direct a focus on the climate change–agriculture nexus and has united the agriculture, climate change and development communities under one brand.

In this review, we first describe the action areas of the food system transformation framework led by CGIAR/CCAFS and partners as an example initiative that brings together leaders in science, business, farming, policy, and grassroots organizations to identify pathways for a rapid transformation. We then use ground-evidenced cases to analyze how CSA can contribute to a rapid transformation of agriculture and food systems in Africa.

2. Methodology

We used an integrative literature-review approach which is intended to address new emerging topics. As stated by Snyder [14], this type of review often requires a more creative collection of data, as the purpose is usually not to cover all articles ever published on the topic but rather to combine perspectives and insights from different fields or research traditions. Our approach for this review consisted in implementing the following steps to showcase how various ground CSA initiatives and projects across Africa may support the fulfillment of the four action areas of the proposed CCAFS transformation framework. Through the integrative review, we aimed at synthesizing selected works from the literature that may enable the new theoretical framework and its perspectives to emerge [15]:

- In a first step, we briefly explained the theoretical entailment of the four action areas of the food system transformation framework proposed by the CGIAR/CCAFS and partners (Figure 1). The methodology for developing the framework consisted of CCAFS/CGIAR working from 2018 with partners to consider how to achieve this rapid, deep-seated change in food systems. Background papers on strategic areas to foster these reconfigurations were developed and presented at international events accompanied by deep discussions with over 1000 stakeholders from all over the world. More than 100 partner organizations engaged in participatory processes to evaluate and sharpen this strategic agenda, culminating in the report of Steiner et al. [10].
- Then, through a search of the literature, we identified specific projects across Africa that illustrate well how CSA initiatives can be pathways to achieving the goals of each of the four action areas for a rapid transformation. We drew on the climate-smart agriculture literature through Google Search and from our experiences developing and evaluating climate-smart agriculture in Sub-Saharan Africa, much in the context of the CCAFS/CGIAR. Emphasis was on information that can feed the four action areas. This concluded in a selection of 24 studies, as described in Table 1.
- In a third step, we selected as case studies, three climate-smart agriculture options that have been tested in the ground and evidenced with quantitative and qualitative data, to analyze their contributions to a rapid transformation of food systems in Africa. These are mostly studies from CCAFS/CGIAR action research but are sometimes supplemented by non-CGIAR examples.
  - The first case study relates to knowledge generation on CSA technologies and practices for their scaling.
  - The second selected case is about using weather and climate information services to build resilience.
  - The third case is an illustration of science–policy interfacing to mainstream CSA into development policies and plans.
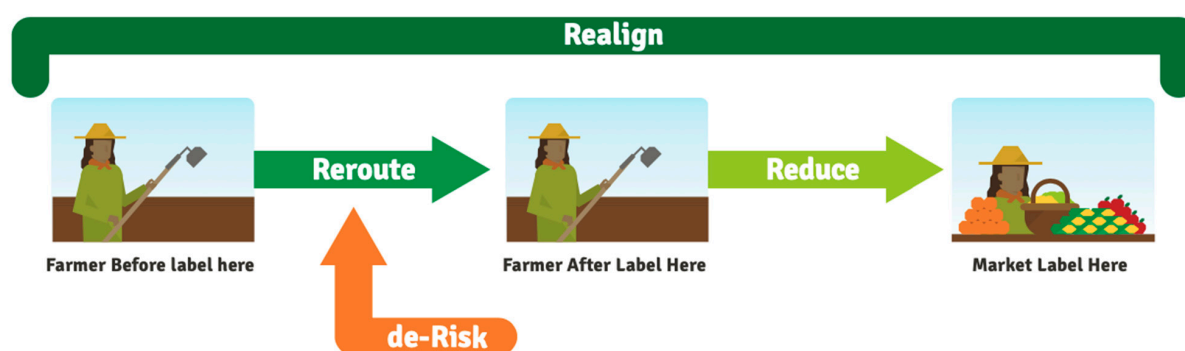
Figure 1. Four action areas for food systems reconfigurations. Source: Steiner et al. [10].

Table 1. List of the literature on ground studies selected to evidence action areas of the transformation framework.

Authors and Year	Geographic Coverage	Study Main Topics	Framework Action Area Potentially Covered	Funding/Managing Organisation
Schroth et al., 2016 [16]	West Africa cocoa belt (Nigeria, Ghana, Côte d'Ivoire, Liberia, and Cameroun)	Patterns, opportunities and limits to adaptation of cocoa	Reroute	International Fund for Agricultural Development (IFAD) and CCAFS
Thornton et al., 2018 [17]	Ethiopia	Markets and public sector actions to for climate-resilient and low emission practices	De-risk	CGIAR/CCAFS
ATA, 2019 [18]	Ethiopia	Markets and public sector actions to for climate-resilient and low emission practices	De-risk	Agricultural Transformation Agency (ATA)
CCAFS, 2015 [19]	Senegal	Climate risk management	De-risk	CGIAR/CCAFS
Hansen et al., 2019 [20]	Sub-Saharan Africa	Climate services for adaptation	De-risk	CGIAR/CCAFS
Kilimo Salama et al., 2014 [21]	Kenya, Rwanda, and Tanzania	Index insurance bundled with agricultural credit and farm inputs	De-risk	Agriculture and Climate Risk Enterprise (ACRE)
Cole et al., 2012 [22]	Global (focus on developing countries)	Index-based micro-insurance for crops	De-risk	International Initiative for Impact Evaluation (3ie).
Index-based livestock insurance (IBLI), 2014 [23]	Kenya	Livestock insurance	De-risk	Index Based Livestock Takaful (IBLT) and International Livestock Research Institute (ILRI)
Gromko et al., 2019 [24]	Kenya, Tanzania, and Nigeria	Food loss and waste	Reduce	CGIAR/CCAFS
Sheahan and Barrett, 2017 [25]	Sub-Saharan Africa	Food loss and waste	Reduce	Cornell University
Global Innovation Lab for Climate Finance, 2019 [26]	West Africa region (Economic Commission of West African States (ECOWAS))	Sustainable finance for CSA	Realign	ECOWAS-Global Innovation Lab for Climate Finance
Bamboo Capital Partners-Injaro Investments, 2019 [27]	West Africa	Sustainable finance for CSA	Realign	Agri-Business Capital (ABC) Funds
Bamboo Capital Partners, Agri-Business Capital (ABC) Funds, 2020 [28]	Cote d'Ivoire	Sustainable finance for CSA	Realign	ABC Funds
Aggarwal et al., 2018 [29]	Global (West and East Africa, Asia, and Latin America)	Climate-Smart Villages approach	Reduce, de-risk, reroute, realign	CGIAR/CCAFS
Ouedraogo et al., 2018 [30]	Ghana, Mali, and Niger	Climate-Smart Villages approach	Reduce, de-risk, reroute, realign	CGIAR/CCAFS

Table 1. *Cont.*

Authors and Year	Geographic Coverage	Study Main Topics	Framework Action Area Potentially Covered	Funding/Managing Organisation
Ouedraogo et al., 2019 [31]	Mali	Climate-Smart Villages approach	Reduce, de-risk, reroute, align	CGIAR/CCAFS
Diouf et al., 2020 [32]	Senegal	Climate risk management	De-risk, reroute, realign	CGIAR/CCAFS
Partey et al., 2020 [33]	Ghana	Climate risk management	De-risk, reroute, realign	CGIAR/CCAFS
Ouedraogo et al., 2015 [34]	Burkina Faso	Climate risk management	De-risk, reroute, realign	CGIAR/CCAFS
Dinesh et al., 2018 [35]	Sub-Saharan Africa	CSA policies	Realign	CGIAR/CCAFS
Global Alliance for Climate-Smart Agriculture (GACSA), 2016 [36]	Africa	CSA policies	Realign	
Common Market for Eastern and Southern Africa (COMESA), East Africa Community (EAC), and Southern African Development Community (SADC), 2011 [37]	COMESA–EAC–SADC region	CSA policies	Realign	COMESA-EAC-SADC
Zougmoré et al., 2016 [38]	West Africa (ECOWAS)	Science–policy interfacing	Realign; reroute	CCAFS/ECOWAS
Zougmoré et al., 2019 [39]	Ghana, Mali, and Senegal	Science–policy interfacing	Realign	CGIAR/CCAFS

CCAFS, Climate Change, Agriculture, and Food Security; CGIAR, Consultative Group on International Agricultural Research; CSA, climate-smart agriculture.

3. Results and Discussions

3.1. Reconfiguring Food Systems in Africa: What Is the Appropriate Framework and the Relevant Action Areas?

The global community is far from achieving the Sustainable Development goals (SDG) and the current COVID-19 pandemic jeopardizes the achieved advances. For example, according to the Global Report on Food Security [40], 135 million people suffer from acute hunger largely due to man-made conflicts, climate change and economic downturns. The COVID-19 pandemic could now double that number, putting an additional 130 million people at risk of suffering acute hunger by the end of 2020 [41,42]. The food systems and their transformation is key to achieving the SDG goals. Food systems are linked to all the SDG's and to every aspect of life and survival on our planet. The growing literature concludes that current food systems are not sustainable and are failing [2]. The main bottlenecks are its inability (i) to produce greater quantities of food to feed a growing world population, (ii) to meet nutritional needs, (iii) to benefit everyone equally and equitably, and (iv) the negative impacts of food systems on the environment [43].

The Food System Transformation Initiative led by CCAFS with more than hundred partners, proposes a framework with four interlocking action areas for food systems reconfigurations [10]. The action areas include the following:

1. Reroute farming and rural livelihoods to new trajectories;
2. De-risk livelihoods, farms, and value chains,
3. Reduce emissions through diets and value chains and
4. Realign policies, finance, support to social movements, and innovation. In continuation, we highlight in more detail, the important actions required in the African context.

(i) Reroute farming and rural livelihoods to new trajectories that both reduce emissions and are climate-resilient. Ensure zero agricultural land expansion on high carbon landscapes is a key component. Most agricultural expansion in carbon-rich landscapes such as coffee/cocoa plantations, is driven by only a few market commodities [44] and often due to low yield, such as for example cocoa production in West Africa. Schroth et al. [16] explain how CSA practices can be targeted along a climate change impact gradient in the West African cocoa belt: In the case of little affected zones, practicing sustainable intensification is recommended. However, for moderately affected zones, diversification and

agronomic adjustments of farming practices, such as targeted shade and soil management, are needed. Gradual crop changes will be required to utilize and restore severely affected zones. If soundly implemented, the above CSA practices can support cocoa production system to become climate-smart. An example on how to enable markets and public sector actions to incentivize climate-resilient and low emission practices comes from the Ethiopian Agricultural Transformation Agency (ATA). 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 [17,18]. This land restoration has induced significant vegetation cover through the growth of fruit trees, therefore contributing to create low-carbon emission landscapes through increased carbon sequestration.

(ii) De-risk livelihoods, farms, and value chains to deal with the increasing vagaries of weather and extreme events; secure, resilient livelihoods and value chains through early warning systems and adaptive safety nets are essential. CCAFS collaborated with the Senegalese National Meteorological Agency (ANACIM) to develop weather and climate information services (WCIS) that are relevant to farmers on a broad scale. As of August 2015, seasonal forecasts are transmitted nationwide through 102 rural community radio stations and SMS, potentially reaching 7.4 million rural people across Senegal. Climate information in Senegal is now considered an agricultural input just like seeds, fertilizers and equipment, which are at the basis of production [19,20]. An impact assessment study revealed that the Use of CIS in Senegal led to 10–25% increases in household income [45]. Helping farmers make better choices by de-risking their farming activities has proven successful in East Africa (Kenya, Rwanda and Tanzania), where the Agriculture and Climate Risk Enterprise (ACRE) recently scaled to reach nearly 200,000 farmers, bundling index insurance with agricultural credit and farm inputs [21]. ACRE, which is a licensed insurance intermediary that provides risk management solutions to reduce agricultural and climate risks, has built on strong partnerships with regional initiatives such as M-PESA (M for mobile, *pesa* stands for money in Swahili) mobile banking. The insurance is designed so that farmers may insure their farm inputs against drought and excess rain and yield shortfall. The insurance covers input loans provided to farmers by the agriculture service provider. The method allows to insure farms as small as one acre as well as larger farms by replacing costly farm visits with measurements from weather stations to approximate actual farm losses. By doing so, this agricultural micro-insurance scheme effectively reduces the impact of severe weather and support increased investment in farm productivity. Insured farmers are able to buy certified seeds and invest in fertilizer instead of planting kept seed and forgoing investing in soil nutrients. Also, in the years following droughts, insured farmers can continue farming as they had before the drought, while their uninsured neighbors continue to feel the negative impact of the loss for many more seasons [21].

Another example of CSA practice that helped de-risk farms and livelihoods is the Risk reduction, Risk transfer, Prudent Risk taking, Risk reserves (R4) initiative in Ethiopia and Senegal. Launched by the World Food Program and Oxfam, the program has scaled unsubsidized index insurance to over 20,000 poor smallholder farmers who were previously considered uninsurable, using insurance as an integral part of a comprehensive risk management portfolio [22]. Moreover, the Index-Based Livestock Insurance (IBLI) project in Kenya and Ethiopia demonstrates innovative approaches to insuring poor nomadic pastoralists in challenging circumstances [23].

(iii) Reduce emissions from diets and value chains, targeting health and climate outcomes. Reducing food loss and waste is central to the three pillars of CSA, to increase food security and resilience (CSA adaptation pillar), decrease emission through wasting valuable agricultural products (CSA mitigation pillar), and increase productivity of food systems (CSA productivity pillar). Examples from Sub-Saharan Africa show that reducing food loss can provide economic returns, while also reducing emissions [24]. Indeed, through food loss and waste, there is a waste of all the natural resources used for growing, processing, packaging, transporting, and marketing food, therefore a carbon footprint

attached to this food loss and waste [25]. Approximately 10–20% of cereal production in Sub-Saharan Africa is lost post-harvest, resulting in decreased farmer income and food insecurity [24]. 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. Another example could be the use by many farmers of some form of chemical or natural spray during home-based storage as a means of keeping pests and insects away from food, therefore mitigating post-harvest losses. A review study by Sheahan and Barrett [46] reported that the largest known promotion scheme of chemical protectants in storage is via Malawi's input subsidy program, which subsidized maize storage chemicals between 2009 and 2012 alongside inorganic fertilizer and improved seed varieties. Farm-household level impacts include an increase in the probability of adopting improved maize varieties and increases in total area and share of area planted to improved maize.

(iv) Realign policies, finance, support to social movements, and innovation to facilitate action in the above action areas. Unlock billions in sustainable finance is paramount in this. Financing the transformation to low-carbon and resilient global food systems will require much larger investments in climate-smart agriculture, specifically from domestic budgets and the private sector. To overcome this financing gap, it will be necessary to blend public and private finance to help achieving climate-smart agriculture objectives while meeting the risk-return profile of different investors. In addition, innovative financial mechanisms and delivery channels will need to be developed to ensure that smallholder farmers and agribusiness can access the capital they need to increase their productivity, build their resilience, and help reduce greenhouse gas emissions. The West African Initiative for Climate-Smart Agriculture (WAICSA) led by the Economic Community of West African States (ECOWAS), is a great example to show how to promote CSA in order to build resilience among smallholder farmers. Climate-smart agriculture (CSA) can offer smallholders a way to better absorb climate shocks and sustainably increase productivity and income. However, unaffordable financial services coupled with lack of information and the high upfront costs of implementing CSA practices limit the ability of smallholder farmers in West Africa to adopt CSA practices. WAICSA provides financial and technical support to incentivize the adoption of climate-smart agriculture and increase local financial institutions' capacity for climate-smart lending. According to the Global Innovation Lab for Climate Finance [26], if brought to scale, WAICSA has the potential to improve the food security of 90,000 smallholder farming households in the region and convert over 185,000 hectares to climate-smart agriculture. The fund can also contribute to mitigating up to 2 million tons of CO_2 emissions a year, which is equivalent to over 4 billion miles of driving.

Another example is the Agri-Business Capital (ABC) funds sponsored since 2019 by IFAD and proposing an innovative approach for attracting much needed capital to rural areas and to underserved segments of agribusiness value chains in developing countries [27]. The ABC fund is an example of blended finance, in which capital from multilateral organizations is used to attract private money. In particular, it catalyzes blended capital and provides technical assistance to investees through a dedicated facility. The ABC Fund provides loans and equity investments adapted to the needs of rural SMEs, farmers' organizations, agri-preneurs and rural financial institutions. It particularly targets commercially viable ventures that can help create employment, in particular for youth and women, and improve rural livelihoods. The fund also prioritizes climate-smart projects that promote sustainable production. The ABC Fund has made its first investment in Socak Katana, a cocoa cooperative in the North Western region of Côte d'Ivoire. This investment is the first in a series of investments in cocoa cooperatives that aim to support and help 10,000 farmers achieve greater revenue and market access. It will also provide technical assistance and training to its member-farmers [28].

3.2. Analysis of Ground CSA Case Studies for Their Contribution to Rapid Transformation of Food Systems

3.2.1. Generating Knowledge on CSA Technologies and Practices for Their Scaling Up/Out: Lessons from the Climate-Smart Village Approach

One factor that contributes to low uptake of new technologies is that development practitioners lack evidence of how the innovations can be practically incorporated into agricultural systems. They need to know how farmers can achieve synergies and minimize trade-offs in implementing multiple interventions on real farms. Climate change complicates this because its impacts will vary across locations. Effective implementation therefore requires an integrated approach in which science, technology, and decision-making interact with local socioeconomic conditions and cultures [47].

In the context of current and projected impact of climate change, experts have proposed several technological, institutional, and policy interventions to help farmers adapt to current and future weather variability and to mitigate greenhouse gas (GHG) emissions. The climate-smart village (CSV) approach is a participatory method of performing agricultural research for development that robustly tests technological and institutional options for dealing with climatic variability and climate change in agriculture. CSVs are "ground laboratories" and learning sites where we test and validate several agricultural interventions in an integrated manner with the communities organized in a village innovation platform with dedicated socially differentiated groups (e.g., women, men, and youth). They work closely with other partners, such as national research and extension services, NGOs, and the private sector. Lessons learned from the CSV are used for scaling up/out to other sites and for policy makers. The approach incorporates evaluation of climate-smart technologies, practices, services, and processes relevant to local climatic risk management. It also identifies opportunities for maximizing adaptation gains from synergies across different interventions, as well as recognizing potential maladaptation and trade-offs. The approach also ensures that these interventions are aligned with local knowledge and link into development plans [29].

As a pilot, CCAFS has supported the setup of about 36 CSV sites around five regions in the world, of which six are located in East Africa (Nyando and Wote in Kenya, Lushoto in Tanzania, Borana in Ethiopia, Hoima, and Rakai in Uganda) and five in West Africa (Lawra-Jirapa in Ghana, Yatenga in Burkina, Kaffrine in Senegal, Cinzana in Mali, and Fakara in Niger) [48].

In a study aiming to prescribing context-specific solutions that foster the scaling up of CSA technologies and practices in West Africa, Ouedraogo et Al. [30] determined the top ten CSA technologies and practices adopted in the CSVs of Ghana, Mali and Niger, and analyzed the reasons and constraints to their adoption. Table 2 presents the top ten adopted CSA technologies and practices in the three countries.

Table 2. Top ten adopted CSA technologies and practices in the three countries (%).

Rank	Ghana (*n* = 270)	Mali (*n* = 300)	Niger (*n* = 300)
1	Intercropping (95.1)	Farm mechanization (96.7)	Crop association (94.3)
2	Crop rotation (95.1)	New crop (95.3)	Organic/compost manure (89.0)
3	Organic/compost manure (90.2)	Organic/compost manure (90.0)	Farmer managed natural regeneration (FMNR) (88.7)
4	Early sowing/planting (81.8)	Monoculture (84.0)	Mulching (77.7)
5	Agroforestry/tree planting (61.5)	Crop association (78.0)	Early sowing/planting (64.7)
6	Use of climate information (59.7)	Farmer managed natural regeneration (FMNR) (73.3)	Improved Variety (53.3)
7	Contour farming (57.7)	Crop rotation (72.7)	New crop (48.3)
8	Minimum tilling (56.4)	Micro-dosing (71.0)	Monoculture (46.7)
9	Late sowing/planting (50.2)	Improved Variety (66.0)	Agroforestry/tree planting (43,7)
10	Monoculture (46.5)	Use of climate information (65.3)	Zai/tassa (42.6%)

Source: Ouédraogo et al. [30]; *n= number of farmers.*

It shows that the type of CSA options as well as the level of their adoption vary from a site to another, therefore indicating that the adoption of CSA may be context specific and based on the needs and priorities of farming communities. The most adopted technologies in all three countries were the use of organic manure/compost and crop association/intercropping which were adopted by more than 90% and 78% respectively in all the three CSV site. In the CSV site of Ghana, the most adopted CSA options were intercropping, crop rotation, organic/compost manure, early sowing/planting, with more than 80% of adoption rate. In Niger the most adopted options are crop association, organic/compost manure, assisted natural regeneration with more than 80% of adoption rate. In Mali, significant differences in the observed and potential adoption rates of the CSA technologies and practices, notably drought tolerant crop varieties, micro-dosing, organic manure, intercropping, contour farming, farmer managed natural tree regeneration (FMNR), agroforestry and climate information service [31]. The most adopted technology was the organic manure (89%) while the least adopted was the intercropping (21%). The observed adoption rate varied from 39% to 77% according to the CSA options while the potential adoption rates of the technologies and practices ranged from 55% to 81%. This implies an adoption gap of 2% to 16% due to the incomplete diffusion (lack of awareness) of CSA technologies and practices which must be addressed by carrying out more actions to disseminate these technologies in the CSV. Results showed that education, number of workers in the household, access to subsidies, and training have a positive effect on the adoption of most of the CSA technologies and practices. In the case of Mali, the adoption of drought tolerant varieties and micro-dosing are positively correlated with access to subsidies and training (Table 3). The likelihood of adopting micro-dosing is increased by 20.00%, 14.00%, and 14.00% with access to subsidies, training on climate information service and use of animal traction, respectively.

Table 3. Marginal effect from probit estimation of determinants of adoption of CSA practices.

	Drought Tolerant Variety	Micro-Dosing	Inter-Cropping	Contour Farming	FMNR	CIS
Education	0.03	−0.07	0.06	−0.19 **	0.26 ***	−0.17 ***
	(0.06)	(0.05)	(0.05)	(0.08)	(0.06)	(0.05)
Number of workers in household	0.005	0.001	−0.01 ***	0.004	0.02 ***	0.004
	(0.01)	(0.004)	(0.004)	(0.006)	(0.007)	(0.005)
Year of experience in farming	0.001	−0.0004	0.002	−0.005 *	−0.0004	0.004 **
	(0.002)	(0.001)	(0.002)	(0.003)	(0.001)	(0.002)
Total land size	0.0003	−0.0001	0.003	−0.001	−0.0001	0.003
	(0.003)	(0.003)	(0.003)	(0.005)	(0.004)	(0.004)
Access to credit	−0.11	−0.07	0.02	−0.02	0.04	0.20 ***
	(0.08)	(0.07)	(0.06)	(0.10)	(0.06)	(0.04)
Access to subsidy	0.13 **	0.20 ***	0.001	−0.04	−0.16 **	0.14 ***
	(0.06)	(0.04)	(0.05)	(0.08)	(0.07)	(0.06)
Animal traction	0.15 **	0.14 **	0.11 **	0.13	−0.01	−0.14 ***
	(0.06)	(0.05)	(0.05)	(0.08)	(0.05)	(0.05)
Training on choice of variety	0.11 *	0.05	0.08 *	0.12	−0.005	−0.02
	(0.05)	(0.05)	(0.05)	(0.07)	(0.05)	(0.05)
Training on CIS	0.24 ***	0.14 **	0.06	−0.21 **	−0.10	0.20 ***
	(0.06)	(0.06)	(0.05)	(0.08)	(0.06)	(0.06)
Number of off-activities	0.06	0.03	0.02	−0.07	0.06	0.03
	(0.05)	(0.05)	(0.04)	(0.07)	(0.05)	(0.05)
Holding a phone	0.11	0.02	0.09	0.24 **	−0.17 ***	−0.04
	(0.10)	(0.08)	(0.08)	(0.12)	(0.05)	(0.08)
Constant	−0.90 **	0.066	−0.170	0.12	0.738	0.54
	(0.38)	(0.39)	(0.389)	(0.44)	(0.43)	(0.47)
Number of observations	286	278	284	211	285	258
Log likelihood	−154.70	−133.40	−121.35	−127.46	−138.63	−113.86
LR chi2	45.26 ***	37.91 ***	24.67 **	35.06 ***	40.49 ***	65.69 ***
DF	11	11	11	11	11	11
Pseudo R2	0.13	0.12	0.10	0.12	0.13	0.22

Robust standard error in parentheses (); *** Significant at 1%, ** significant at 5% and * significant at 10%. Number of farmers = 300. Source: Ouédraogo et al. [31]. CIS, climate information services.

Major constraints associated with the use of CSA options are the inappropriateness of practices, the lack of information about the CSA option, limited technical capacity to handle the CSA options, and the illiteracy of farmers. Table 4 shows that 39% of respondents thought that the FMNR was not a suitable technology. About 36%, 35%, 31%, and 20% reported the same for improved varieties, intercropping, micro-dosing, and organic manure, respectively. The illiteracy of farmers coupled with the lack of technical capacity are also part of constraints that respondents faced in adopting a CSA practice. Some respondents also raised up the issue of information dissemination on the CSA practices. The study suggests that efforts should be focused concomitantly on the diffusion of CSA options as well as the lifting of their adoption barriers.

Table 4. Constraints to adoption of CSA technologies and practices in Mali (in % of respondents).

	Drought Tolerant Variety	Organic Manure	Micro-Dosing	Intercropping	Contour Farming	Agroforestry	Farmer Managed Natural Tree Regeneration	Climate Information Services
Illiteracy of farmers	16.00	9.34	10.77	10.47	19.39	9.98	8.87	33.24
Limited technical capacity	26.60	40.66	24.12	24.61	26.06	15.91	9.83	15.29
Lack of information about the technology/practice	16.20	25.68	25.76	9.16	29.09	21.14	17.27	38.24
Unappropriated technology/practice	36.00	20.62	31.38	35.08	16.36	19.24	39.09	8.82
Limited funds	5.00	1.75	6.79	3.93	4.24	9.50	1.92	3.53
Land insufficiency	0.00	0.00	0.00	0.00	0.30	12.35	5.04	0.00
Lack of water	0.00	0.58	0.23	0.26	0.00	11.16	12.23	0.00
No specific constraint	0.20	1.36	0.94	16.49	4.55	0.71	5.76	0.88

Number of farmers = 300. Source: Ouédraogo et al. [31].

Through the CSV approach, the research-evidence knowledge on potential CSA options supports the Food Systems Transformation with the identification of technologies and practices that are relevant for the various action areas of the proposed framework. For instance, results from Table 1 suggest that among the top ten CSA options, some like the agroforestry/tree planting and FMNR, micro-dosing, can contribute to the action area on reducing emissions, while the use of WCIS, late or early sowing, can help for the action area on de-risking. Crop rotation, farm mechanization, and use of new crops and improved varieties certainly help to rerouting farming to new trajectories. Moreover, the setup of innovation platforms with differentiated socially organized groups (women, men, and youth) appears an asset to support institutional change and social movements, thus contributing to the action area on Aligning.

3.2.2. Using Weather and Climate Information Services (WCIS) to Build Resilience

In the quest to improve the capacity of farmers to better manage climate-related risks and build more resilient livelihoods in West Africa, there have been various initiatives focusing on the following: (i) designing tailored climate information services and (ii) communicating the results appropriately to farmers for their farm management decision-making [19]. Since 2011, substantial successes have been achieved, particularly in Senegal and Ghana. In Senegal, a collaboration between scientists, the national meteorological agencies and 105 rural community-based radio stations, resulted in the promotion of economic development through communication and local information exchange, and seasonal forecasting, which allowed to reach about 7.4 million rural dwellers across the country [19]. Climate information Services have benefited fisher-folks, pastoralists and crop producers in managing farm-related, and other livelihood, activities. In addition to informing the action area on de-risking, this example illustrates how through developing partnerships among various national actors, it was possible to induce rapid transformation

of the national climate information system. Indeed, it contributed to accelerate the access of million users to WCIS.

A study by Diouf et al. [32] used a stratified two-stage sampling method to randomly select about 1500 farmers (56% men and 44% women), of which 9562 benefited from WCIS while 2922 were non-beneficiaries. Beneficiaries are those who receive weather and climate services from the National Meteorological Service and through community radios and social networks. Non-beneficiaries are those who do not receive WCIS. Through the instrumental variables' technique, one of the statistical tools for impact evaluation when it is not possible to create a comparison group randomly [49], they predicted the program participation, then followed by the estimation of the program impact based upon the prediction. The study reported that users (men and women) of the seasonal forecast in Senegal gained statistically significant higher yields than the non-users (158 kg/ha or 22%) and 140 kg/ha or 19%) respectively, for millet and rice crops. Despite its probabilistic nature and imperfection, seasonal forecast information helps farmers to better manage climatic risks through making informed-decisions on the planning of farm operations. The impact of the use of seasonal forecast is greater for men than women on millet yields (202.7 kg/ha (28%) vs. 16.7 kg/ha (2.3%)) and rice (321.33 kg/ha (34%) vs. 25.3 kg/ha (−3.87%)). However, it is greater for women on maize (210 kg/ha vs. 105 kg/ha). According to the same authors [32], there are three main reasons explaining why the use of seasonal forecast induces sex-differentiated benefits:

5. Traditionally, there is crop specialization by gender in rural areas in Senegal: Women cultivate cereal crops called food crops, while men focus mainly on cash crops.
6. Women suffer from inequalities in terms of access to land and labor. They have smaller areas of land, which has resulted from historical social and legal barriers that have limited their access, their educational opportunities, and their economic advancement in rural areas.
7. Women also have limited access to credit and financial resources to enable them to make appropriate decisions. In addition to this, women are less adaptive because of financial or resource constraints due to male domination in receiving information and extension services and because available adaptation strategies tend to create higher labor loads for women. Users of seasonal forecast had also a positive and significant impact of $41 per ha on the income (Table 5). The additional income is more important for men ($56) than women ($11).

Table 5. Comparison of incomes generated through climate information services by gender.

Sex	Modalities of Users	Number of Farmers	Mean (XOF)	Standard Deviation
Male	Non-users	541	140,070.8	125,939.4
	Users	73	167,669.1	122,849.3
	All	614	143,352	125,795.4
	Difference		−27,598.3 **	
Female	Non-users	464	130,605	120,289.9
	Users	41	139,953.9	182,833
	All	505	131,364	126,301.7
	Difference		−9348.92	
Total	Non-users	114	157,701.4	147,062.8
	Users	1005	135,700.5	123,392.6
	All	1119	137,941.9	126,109
	Difference		22,000.85	12,451.28

Note: ** = significant at 5% (Student's *t*-test). Source: Diouf et al. [32]. XOF is the ISO currency code of the West African CFA Franc.

Similar results were obtained in Northern Ghana, Upper West Region, where downscaled seasonal forecast information had been disseminated since 2011 to farmers through

mobile phone technologies (Esoko platform) [33]. Farmers used seasonal forecasts to make strategic decisions such as when to start land preparation, when to plant, selection of crop varieties, and when to apply manure or chemical fertilizers. Partey et al. [33] reported that the use of seasonal forecast in Northern Ghana increases the productivity of rural communities and affects men and women differently.

In a bid to sustain the delivery of climate information services to farmers through digital-led mechanisms (mobile phone platforms), a public–private partnership (PPP) business model was developed in 2017 to enhance existing partnership of Esoko with private companies (Toto agric. and aWhere, Vodafone Ghana) and public institutions (GMet, the Council for Scientific and Industrial Research (CSIR), and the Ministry of Food and Agriculture (MoFA)) and farmers (Figure 2). Roles and responsibilities of each of the above involved actors in the business model have been well defined and consensually agreed upon to allow smooth implementation of the model [50]. Preliminary results show that more than 300,000 farmers (21% women) are paying an agreed $US 0.2 monthly subscription fee to receive CIS through the PPP. The PPP has been strategically linked to the Planting for Food and Jobs initiative of the Government of Ghana to make a strong case for the mainstreaming of climate information services into agricultural development plans, programs, strategies, and policies in Ghana [50].
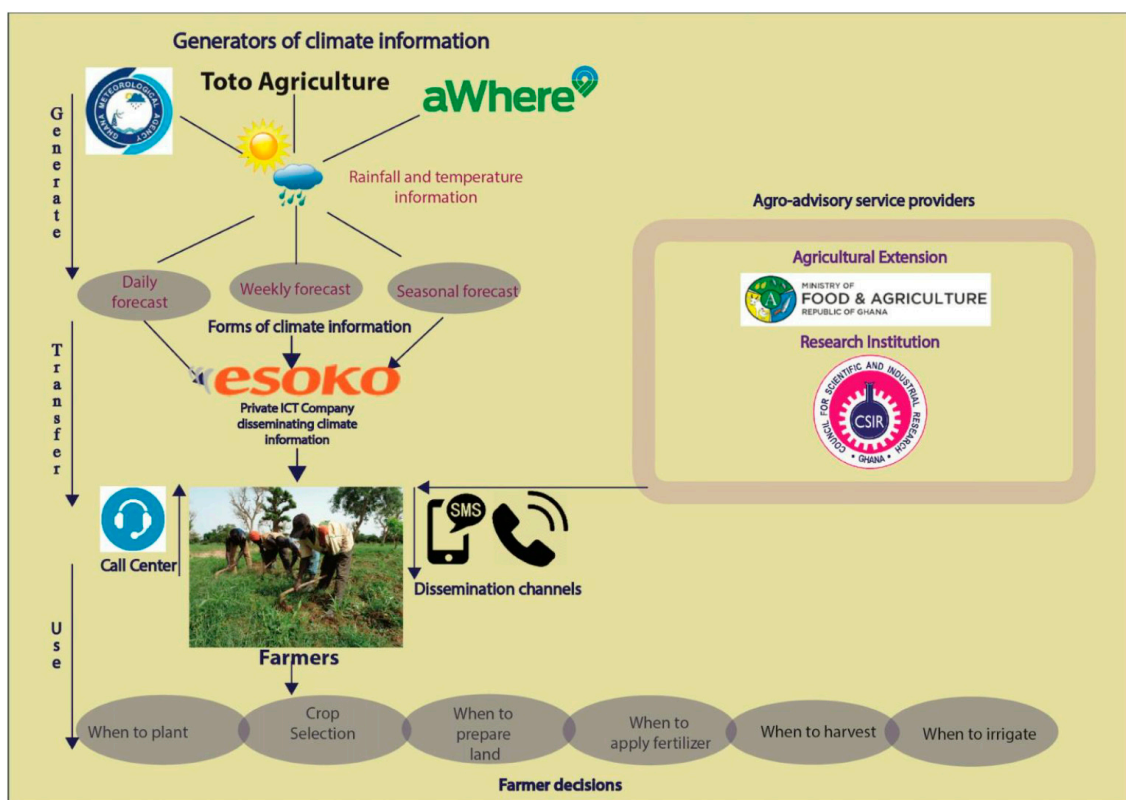
Figure 2. Public–private partnership model for climate information services in Ghana (source: Partey et al. [44]).

Like for the above Senegal example, this case study from Ghana supports the de-risking action area through the dissemination for use of WCIS by farmers. It also shows how developing a business model between public- and private-sector actors could generate institutional partnership and financial mechanisms that sustain the delivery of WCIS. This supports the action area on realigning policies and finances.

Furthermore, ROPPA, the West Africa farmers' organizations network, and the agricultural value chain programs initiated by CCAFS in Burkina Faso (PROFIL) and Senegal (PAFA), also disseminated seasonal forecast information and climate-smart agricultural options to farmers from various agricultural sectors as well as throughout their national

constituencies [34]. A cost–benefit analysis in Burkina Faso showed that farmers exposed to climate information used fewer local seed and more improved seed for cowpea and sesame production [34]. They also used more inorganic fertilizers for sesame production (23 kg/ha for WCIS-exposed farmers versus a mere 1 kg/ha for non-exposed ones). The increased inorganic fertilizers application is probably due to the confidence gained by farmers that through using WCIS, fertilizers will be applied at the right moment vis-à-vis rainfall occurrence, therefore reducing risks of any fertilizers wash out and also, increasing nutrient use efficiency. With this cash crop, farmers tend to invest more in fertilizers if they feel less uncertain about climate hazards. Cowpea producers exposed to climate information obtained higher yields and, at the same time, lower input costs. Their gross margins were therefore found to be higher compared to non-exposed farmers. A further study by Ouédraogo et al. [30] reported that 63% of respondents were willing to pay for climate information services (CIS) such as seasonal climate forecast (SCF), decadal climate information (10-DCI), daily climate information (1-DCI) and agro-advisories. The predicted value for the WTP was XOF 3496 for SCF, XOF 1066 for 10-DCI, XOF 1985 for 1-DCI, and XOF 1628 for agro-advisories. The study also showed that several socioeconomic and motivation factors have greater influence on farmers' WTP for CIS. These included the gender, age, education of the farm head, and the awareness of farm head to climate information.

3.2.3. Science–Policy Interfacing to Mainstream CSA into Development Policies and Plans

Science–policy engagement efforts are crucial to ensure that scientific findings from agricultural research for development inform actions of governments, private sector, non-governmental organizations (NGOs), and international development partners, accelerating progress toward upper-level goals.

This section summarizes key findings from Dinesh et al. [35] who synthesized CSA initiatives existing in East, West, and Southern Africa sub-regions that support implementation of the action area on realigning policies and finance to mainstream CSA into development programs. Most of them are closely linked with continent-wide initiatives. The New Partnership for Africa's Development (NEPAD) agency is leading the implementation of the African Union-NEPAD Agriculture Climate Change Programme, which aims to have 25 million farm households practicing CSA by 2025 [36]. A key continental initiative supporting this effort is the Africa CSA Alliance, a partnership between NEPAD Agency and five international NGOs (CARE, Catholic Relief Services, Concern, Oxfam, and World Vision), and linking closely with previous continental initiatives to transform agriculture in Africa, such as the Comprehensive Africa Agriculture Development Program (CAADP). The Alliance aims to reach at least 6 million farm households with CSA thus contributing to NEPAD's 2025 goal of reaching 25 million farm households [36].

In East and Southern Africa, the three Regional Economic Communities, Common Market for Eastern and Southern Africa (COMESA), East African Community (EAC), and Southern Africa Development Community (SADC) collaborated on a project that is supporting adoption of conservation agriculture, supporting investments in national CSA programs, and addressing the linkages between agriculture, forestry and land use and Reduced Emissions from Deforestation and Degradation (REDD). The goal is to bring significant livelihood and food security benefits to at least 1.2 million small-scale farmers during 2013–2017 [37].

In West Africa, the West African CSA Alliance (WACSAA) was established by the Economic Community of West African States (ECOWAS) in 2015 to support efforts in the region [38]. The Promotion of Smart-Agriculture towards Climate Change and Agro-ecology transition in West Africa is a regional initiative led by ECOWAS and covers 15 countries. The initiative aims to ensure adoption of CSA practices by 25 million households by 2025, and includes two steps: firstly, the spread of best practices through public policies (involvement of public services in charge of agricultural and environmental policies) and, subsequently, farmers' training and support by NGOs and producers (involvement of producer organizations and operators).

The above regional efforts are complemented by national and local efforts. One successful example at the national level is the CCAFS West Africa initiative of setting up multi-stakeholder national science–policy dialogue platforms on climate-smart agriculture (CSA) in Ghana, Mali, and Senegal, with the aim to use scientific evidence to create awareness of climate change impacts on agriculture and advocate for the mainstreaming of climate change and CSA into agricultural development plans [39]. Five years after operation, we assessed how the modes of operation and achievements of these CSA platforms improve our understanding of the science–policy interfaces of agricultural and climate change decision making. The operations and achievements of the platforms were analyzed vis-à-vis three determinants: (1) their mandate of influencing policy decision-making; (2) knowledge generation for effective science–policy interaction; and (3) engagement and communication pathways for effective science–policy interaction.

Results showed that these platforms constitute an innovative approach to effectively engaging decision-makers and sustainably mainstreaming climate change into development plans. Effective science–policy interaction requires the following: (a) institutionalizing dialogue platforms by embedding them within national institutions, which improves their credibility, relevance and legitimacy among policymakers; (b) two-way communication, which contributes substantially to the co-development of solutions that address climate change vulnerabilities and impacts; and (c) relevant communication products and packaging of evidence that aligns with country priorities, which facilitates its uptake in policy-making processes.

Examples of successful science-informed policies and plans are for instance the development by the platform of Ghana's first National CSA Action Plan, targeted at ensuring the ground-level operationalization of the eight program areas of the agriculture and food security focus areas of Ghana's National Climate Change Policy (NCCP). The NCCP was developed by a multi-stakeholder group to affirm Ghana's ambition to mitigate risks posed by climate change [51]. In collaboration with the Ministry of Food and Agriculture (MoFA), in 2015 the platform developed and launched the country CSA action plan (2016–2020). Specific strategies were formulated in the CSA action plan to contribute to developing climate-resilient agriculture and food systems for all agro-ecological zones, as well as the human resource capacity required for a climate-resilient agriculture promotion in Ghana. Its development was made possible through the active engagement of various public and private entities in Ghana through dialogue and knowledge exchanges. Nowadays, the national platform is being scaled up to district level with currently 11 district level platforms for CSA promotion.

In Senegal, the national platform engaged with policymakers using workshops as means of sharing knowledge on the climate change implications for the agricultural sector and rural sector development programs. Platform members were asked to conduct an in-depth analysis of the level of climate change mainstreaming into activities defined in the country's major Program for Accelerated Agricultural Development (PRACAS). The PRACAS is the agricultural component of the presidential plan for an emerging Senegal by 2035 (PSE). Recommendations from the analysis were discussed during a high-level policy event organized in 2016 with attendance of national elected officials such as Parliamentarians, members of the Social, Environmental and Economic Council (https://www.Integration_cc_au_senegal, accessed on 8 January 2021). Following the event, the recommendations have been integrated into the PRACAS. In recognition of the immense contribution of the platform to CSA promotion in Senegal, the platform received a state-funding support of about US$ 200,000 in 2016, which has allowed the downscaling of the national platform into 13 district-level platforms.

4. Conclusions

This review showed that a rapid transformation of food systems in Africa can be possible, provided sound technologies and practices, as well as mechanisms and enabling conditions are developed to reroute farming trajectories, reduce risks, minimize the envi-

ronmental footprint of food systems, and realign the enablers of change. Climate-smart agriculture can play a key role in driving the change through innovative actions that mainstream the three pillars (productivity/adaptation/mitigation) in an effective way. This may consist in (1) the implementation of relevant climate-smart technologies and practices to reroute farming and rural livelihoods to new climate-resilient and low-emission trajectories; (2) the development and application of weather and climate information services (WCIS) that support de-risking of livelihoods, farms, and value chains in the face of increasing vagaries of weather and extreme events; (3) the use of climate-smart options that minimize waste of all the natural resources used for growing, processing, packaging, transporting, and marketing food, and therefore mitigating the carbon footprint attached to these food loss and waste; and (4) the realignment of policies and finance that facilitate action in the four proposed action areas through the identification of news ways to mobilize sustainable finance and create innovative financial mechanisms and delivery channels. In this perspective, a co-production perspective must be prioritized to engage the diversity of actors to generate the knowledge evidence on potential CSA technologies and practices. This knowledge must be communicated in appropriate formats among the scientific, policy, and farmers communities, together with capacity building efforts to raise capacity and investment for widespread implementation.

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