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Country-specific challenges to improving effectiveness, scalability and sustainability of agricultural climate services in Africa

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Climate services are playing an increasing role in efforts to build the resilience of African agriculture to a variable and changing climate. Efforts to improve the contribution of climate services to agriculture must contend with substantial differences in national agricultural climate services landscapes. Context-specific factors influence the effectiveness, scalability and sustainability of agricultural climate service, but in ways that are challenging to anticipate. In the context of six countries (Ethiopia, Ghana, Kenya, Mali, Senegal, Zambia), this paper addresses the need to consider differing national contexts when developing strategies to make agricultural climate services in sub-Saharan Africa more effective, scalable and sustainable. Based on authors' collective firsthand knowledge and a review of information from secondary sources, we identify key strengths and weaknesses of climate services relative to agriculture sector needs in the focus countries; and assess factors that have contributed to those differences. Focus countries differ substantially in areas such as the degree of public support, alignment of services with agricultural needs, service delivery channels, degree of decentralization, and public—private-sector balance. These differences have been driven largely by differing national policies, delivery capacity and external actors, but not by responsiveness to agricultural sector demands. Building on the analyses of country differences and their drivers, we then discuss four key opportunities to further strengthen the contribution of climate services to agriculture: (a) leveraging farmer demand to drive scaling and sustainability; (b) exploiting digital innovation within a diverse delivery strategy; (c) balancing public and private sector comparative advantage; and (d) embedding climate services in agricultural extension. For each of these opportunities, we consider how different country contexts can impact the potential effectiveness, scalability and sustainability of services; and how efforts to strengthen those services can account for context-specific drivers to manage the tradeoffs among effectiveness, scalability and sustainability.

KEYWORDS

farmers, agricultural extension, National Meteorological Services, digital agriculture, public goods

Introduction

Climate-related risk is a major contributor to food insecurity and an impediment to efforts to improve the livelihoods of smallholder farmers in sub-Saharan Africa (SSA) (Rosenzweig and Binswanger, 1993; Devereux, 2007; Belesova et al., 2019; Hansen et al., 2019a, 2022; Ngcamu and Chari, 2020). Well-functioning climate services are increasingly recognized as a crucial part of efforts to develop more climate-resilient agricultural and food systems in SSA, helping decision-makers understand, anticipate and manage climate-related risks. Effective climate services support farmers to improve their productivity and welfare through a range of climate-sensitive production and livelihood decisions (Tall et al., 2018; Vaughan et al., 2019; Born et al., 2021; Hansen et al., 2022). They can also inform investment decisions by a range of agricultural value chain actors (e.g., input distributors, commodity markets, rural financial services). The wide range of climate-sensitive decisions that farmers and other agricultural decision-makers face creates the need for multifaceted climate services that provide diverse suites of information, across relevant time scales, through multiple communication channels.

As agricultural climate services have moved beyond information generation and pilot demonstrations, the attention of funders and implementers has moved beyond effectiveness to also consider the scalability and sustainability of those services. *Effectiveness* deals with impact of services on decision making, productivity and wellbeing, and with how equitably these benefits are distributed within farming populations. *Scalability*, which deals with numbers of farmers reached, is a priority of several development funders and recent global initiatives. For example, an initiative to transform food systems under a changing climate by 2030,[1] led by the CGIAR research program on Climate Change, Agriculture and Food Security (CCAFS), proposed taking "climate services to scale by connecting 200 million farmers and agribusinesses to ICT-enabled bundled advisory services by 2030" (Steiner et al., 2020, p. 7). The Global Commission on Adaptation (GCA)[2] proposed a goal and commissioned a roadmap for investing in "digital climate advisory services" that build the resilience of 300 million additional small-holder producers by 2030 (Global Commission on Adaptation, 2019; Ferdinand et al., 2021). *Sustainability* deals with the ability to maintain a given level of service in the long term, with particular concern for the impact of inadequate public funding and dependence on project funding cycles on the human and technological capacity of National Meteorological Services (NMS). All three dimensions—effectiveness, scalability and sustainability—determine the degree to which climate services will contribute to climate adaptation and climate-resilient agricultural development goals. Tradeoffs can be expected among effectiveness, scalability and sustainability goals, as different stakeholders prioritize different goals, and different implementation strategies favor different goals at the expense of others.

Efforts to make climate services more effective, scalable and sustainable—relative to agriculture sector needs—must content with substantial differences in national agricultural climate services landscapes and a range of enabling and constraining factors. The factors that have led to differences in national climate service landscapes across SSA are not fully understood. Furthermore, these context-specific factors can be expected to interact with the differing approaches that agricultural climate service implementers and funders bring to the challenge, in ways that are only partially understood and difficult to anticipate.

This paper aims to contribute to our understanding of how efforts to strengthen the contribution of climate services to farmers' livelihoods and agricultural development goals can account for differing country contexts. We first identify key strengths and weaknesses of climate services relative to agriculture sector needs in the focus countries; and assess how differences in agricultural systems, policies, capacity and external actors may have contributed to those differences. Building on the analyses of country differences and their drivers, we then discuss key opportunities to further strengthen agricultural climate services. We consider how different country contexts can impact the potential effectiveness, scalability and sustainability of services; and how efforts to strengthen those services can account for context-specific drivers to manage the tradeoffs among effectiveness, scalability and sustainability.

Our analyses and discussion focus on six African countries (Ethiopia, Ghana, Kenya, Mali, Senegal, and Zambia) (Figure 1)

1 https://www.transformingfoodsystems.com.

2 https://gca.org/about-us/the-global-commission-on-adaptation.

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FIGURE 1
Location of focus countries. Created with https://www.mapchart.net/world.html.

that are part of the Accelerating the Impact of CGIAR Climate Research for Africa (AICCRA) project, which aims to strengthen capacity to use climate services and climate-smart technologies for smallholder agriculture in the western Africa drylands, eastern Africa dry lowlands and highlands, and southern Africa drylands. They were selected for their: (a) political and financial commitment to adapting agriculture to climate change; (b) adequate institutional capacity; (c) demonstrated commitment to engage the CGIAR and mainstream CGIAR science into their national agricultural plans; and (d) participation in regional networks and institutions that can scale out project impacts (Klytchnikova, 2020). Since 2021, the AICCRA project has been working to strengthen farmers' capacity to anticipate and manage climate-related risks through improved climate information and advisory services, in a manner that balances country-specific needs and challenges with coordination and scalability.

Methods

Our study aimed to answer two questions: (a) What are the key strengths and weaknesses of climate services relative to agriculture sector needs in the focus countries? (b) How have country differences in agricultural systems, policies, capacity and external actors influenced the development of agricultural climate services?

Our assessment was informed by authors' collective firsthand knowledge; and a review of information from secondary sources: (a) published and gray literature, (b) publicly available policy documents, (c) institutional websites, and (d) quantitative data (Table 1). The team of authors has firsthand knowledge of many of the relevant institutions and issues from experience working with agricultural and climate institutions in all six focus countries. Available secondary data supported objective comparisons of economically important agricultural value chains, aggregate agriculture-related investment, and ICT capacity among the focus countries. However, we were unable to find comparable quantitative national data related to NMS capacity and budgets, agricultural extension budgets, or donor investment in climate service projects and institutions. Gaps in firsthand knowledge, and in comparable, cross-country data, were filled with a review of qualitative information available from secondary sources.

Results

National agricultural climate service landscapes

The agricultural climate service landscape, and the climate information products that are available to farmers and agricultural value chain actors, differ among the focus countries (Tables 2, 3). Because information is not readily available in forms that allow objective comparisons across these countries, the summaries below are qualitative, based on first-hand information and available secondary sources. Key features that differ among the focus countries include degree of public policy and financial support, the maturity (e.g., diversity, spatial scale, formatting, supporting documentation) of available information relative to agricultural needs, the communication channels employed to deliver services, the degree to which services are decentralized, and the balance of public and private sector engagement in service provision.

Ethiopia

Climate services in Ethiopia are characterized by centralized public sector services, relatively high degree of integration across government ministries and sectors, and co-development of climate services by the Ministry of Agriculture. Ethiopia's National Meteorological Agency (NMA) operates eleven strong but under-utilized Regional Meteorological Centers distributed across the country, yet most of their services are provided from their national headquarters. Participation in climate services is strong across government ministries and sectors, particularly with the Ministry of Agriculture and its technical agencies (Ethiopian Institute of Agricultural Research, Agricultural Transformation Agency), the National Disaster Risk Management Commission (NDRMC), and the Ministry

TABLE 1 Information sources used for each study topic (indicated by grey shading).

Topic	Firsthand knowledge	Literature review	National websites, policy documents	Quantitative data
Current state of agricultural climate services	■	■	■	
Priority agricultural value chains				■
National policy		■	■	
Public investment				■
Agricultural extension capacity	■	■	■	
ICT development		■		■
External climate services community	■	■		

TABLE 2 Key features, strengths and weaknesses of agricultural climate services in focus countries.

Country	NMS	Parent ministry	NFCS status[a]	Strengths	Weaknesses
Ethiopia	National Meteorology Agency (NMA)	Water, irrigation and energy	5	NMS integration within national government and agriculture sector. Ministry of Agriculture co-leadership. Gridded data and advanced online climate information products.	NMS does not use its 11 regional branches effectively to provide decentralized services. Private sector less engaged in climate services than in other focus countries.
Ghana	Ghana Meteorological Agency (GMet)	Communications and digitalization	3	Innovative PPP engages NMA, agriculture sector to provide weather information and advisories for farmers in local languages. Agricultural extension participation.	Lack of public-good climate information targeting agriculture sector. Dependence on a U.S. commercial weather data provider that went out of business. Little user feedback to national organizations.
Kenya	Kenya Meteorological Department (KMD)	Environment and forestry	2	Strong decentralized services in some counties. Co-leadership within the DRR sector. Dynamic, diverse services and delivery channels. Gridded data and advanced online climate information products.	Coordination and redundancy challenges within pluralistic services. Insurance uses global remote sensing products rather than higher quality NMS gridded data.
Mali	*Agence Nationale de la Météorologie* (Mali Météo)	Transport and infrastructure	5	Legacy of a >30-year agrometeorology advisory program. Active national GTP.	Major NMS human, financial, infrastructure resource constraints. Low rural literacy rates constrain effectiveness of mobile phone channels.
Senegal	*Agence Nationale de l'Aviation Civile et de la Météorologie* (ANACIM)	Tourism and air transport	5	Subnational GTP. Innovative PPP provide weather information and advisories for farmers. Gridded data and advanced online climate information products.	Inadequate public investment in NMS. Public agricultural extension not engaged in climate services. Insurance uses global remote sensing products rather than higher quality NMS gridded data.
Zambia	Zambia Meteorological Department (ZMD)	Transport and communications	0	Gridded data and advanced climate information products. New national policies prioritize climate services. Private sector innovation in digital services for farmers.	NMS human resource constraints, limited range of climate information products and communication channels. NMS lacks a public website. Diversity of farmers' local languages.

[a]NFCS stages are 1: baseline capacity assessment, 2: consultation workshop, 3: strategic plan and costed action plan, 4: endorsement, 5: launch, and 6: advanced services implemented through NFCS.

TABLE 3 Available NMS weather and climate information products for each focus country (indicated by grey shading).

Product[a]	Ethiopia	Ghana	Kenya	Mali	Senegal	Zambia
Forecasts						
Weather forecasts	■	■	■	■	■	■
Extreme weather warnings	■	■			■	
Monthly/sub-seasonal	■	■	■	■		■
Seasonal						
• Rainfall total	■	■	■	■	■	■
• Rainfall timing (onset, cessation)		■	■		■	■
• Spell characteristics						■
• Temperature	■	■	■		■	
• Objective forecast system	■	■	■			■
• Probabilistic presentation						
○ terciles	■	■	■			■
○ full distribution	■		■			■
Climatology						
Produce gridded climatology	■	■	■		■	■
Historical rainfall analysis online:	■	■	■		■	■
• Basic (monthly or 10-daily time series and/or seasonal cycles)	■	■	■		■	■
• Daily (frequency, intensity, spells, extremes)	■	■	■		■	■
• Growing season timing (onset, cessation)	■	■	■		■	■
• Historical temperature analysis online	■		■		■	■
Monitoring						
Station data	■	■	■		■	■
Gridded	■	■	■		■	■
Agricultural bulletins						
10-daily	■	■	■		■	■
seasonal	■	*	*			
Sector-focused services (listed on website or bulletins)						
Agriculture	■		■	■	■	■
Health	■		■		■	
Transportation		■	■	■	■	■
Water resource management	■	■	■		■	■
Climate change			■	■	■	

[a]Shading indicates the product is freely available online, at time of writing.

[*] No seasonal agrometeorological bulletin, but potential agriculture and food security impacts are described in the general seasonal forecast bulletin.

of Water, Irrigation and Energy (MoWIE). NMA is also a member of several cross-sectoral committees and working groups. The most prominent one is chaired by the Deputy Prime Minister and members include the different sectoral ministers, which makes decisions about different aspects of DRM. As a result, NMA enjoys very strong government support. NMA provides basic weather forecasts at several lead times (daily, 10-daily, monthly, and seasonal). It was the first NMS in Africa to prepare and issue seasonal forecasts, beginning in 1987. The NMA provides agrometeorological services directly to the public (mainly through radio, TV and Internet, but also directly to smallholder farmers), and through government agencies and non-governmental organizations. Radio remains the most important channel by which farmers access weather and climate information. NMA has an advanced online climate information portal that provides an array of climate information products designed to address needs of expert users from various climate-sensitive sectors. These products are particularly advanced for the agriculture sector, and include rainfed growing season onset and cessation dates, and probability of dry and wet spells, for any location. Although there is no national policy that formally integrates climate services and agricultural extension services, the Ministry of Agriculture and its technical agencies have been proactive about bringing weather and climate information into advisory services for farmers.

Ghana

Ghana's climate services are pluralistic, with an expanding community of non-government actors stepping up to fill gaps in the Ghana Meteorological Agency's (GMet) services for agriculture. GMet provides basic weather forecasts at several lead times, and seasonal forecasts of total rainfall and onset and cessation dates. Although national agriculture policy recognizes the need and encourages GMet to provide localized weather information for farmers, GMet provides little public-good information that is tailored to the agriculture sector (Naab et al., 2019). GMet offers data and customized, fee-based agrometeorological services that largely target development projects, institutions and researchers, as their cost makes them generally inaccessible to smallholder farmers (Anaman et al., 2017). Radio remains the most important channel by which farmers access weather and climate information, supported by call-in programs that allow a degree of interaction (Antwi-Agyei et al., 2021; Sarku et al., 2021). Mobile phone-based services are expanding rapidly with the creation of online climate information dissemination platforms. Agricultural extension also plays an important role in accessing agricultural climate services. Several non-governmental and private sector actors are working to fill the demand for agriculturally relevant services. In northern Ghana, a public-private partnership (PPP) among Esoko-Ghana, GMet, Ministry of Food and Agriculture, Savanna Agricultural Research Institute, and private sector weather information and telecommunications companies provides farmers with downscaled weather and climate forecast information, agricultural advisories and market information *via* mobile phone, in their local languages, on a subsidized fee basis (Partey et al., 2020). While this expanded collaboration between government and other organizations has expanded the flow of information to farmers, limited feedback to national organizations was identified as a weakness (Ofoegbu and New, 2021).

Kenya

Climate services in Kenya show a relatively high degree of maturity, and are characterized by pluralism, decentralization, and strong user orientation and ownership. Kenya seems to have the most mature climate service landscape among the six focus countries in terms of the numbers of farmers reached, diversity of agricultural decision makers engaged, diversity and degree of tailoring of climate information to the needs of the agricultural sector, strength of communication processes used, and integration of climate and agricultural extension services. KMD shifted much of its service delivery to the county level, in response to the 2010 constitution which decentralized much of the authority, finance and services of Kenya's government. The Adaptation Consortium (ADA), led by the National Drought Management Authority (NDMA), provided technical and financial support to develop climate services in a set of pilot counties. This led to the establishment of county climate service plans, County Meteorology Directors employed by KMD, installation of meteorological stations, and regular multi-stakeholder meetings to produce advisory bulletins based on weather and climate information (Adaptation Consortium, 2014). Climate services and agricultural extension services are integrated at the county level through the multi-stakeholder consultation process, which has adopted Participatory Scenario Planning (PSP)—a structured participatory training and planning process developed by CARE International (Ambani et al., 2018). NDMA and KMD are scaling out county climate services across the country. Participatory climate communication, training and planning processes play a greater role in Kenya than the other focus countries. In addition to PSP, climate services have been incorporated into a farmer field school curriculum that is being implemented in Kenya, Tanzania and Uganda (Osumba et al., 2021). Traditional broadcast and print media remain important channels for accessing weather and climate information. Private sector technology companies are particularly active in Kenya's pluralistic climate information and agricultural advisory landscape, across the chain from generation of weather information to delivery to farmers through various mobile phone platforms. The use of global remote sensing climate information products, rather than KMD products, for index-based insurance and several early warning services raises concern about the quality of these services, as uncalibrated satellite rainfall estimates are known to have poor accuracy.

Mali

Climate services in Mali reflect both a long history of services for farmers, and serious resource constraints. The country's agriculture sector benefited from Africa's first and longest-running national agrometeorology advisory program, *Projet d'Assistance Agro-meteorologique au Monde Rural* (Project for Agrometeorological Assistance to the Rural World), funded by the Swiss Agency for Development and Cooperation from 1982 to 2005 (Carr and Onzere, 2018). The project established a national inter-ministerial working group, the *Groupe de Travail Pluridisciplinaire d'Assistance Agro météorologique* (GTPA), to monitor climate conditions, and produce and communicate advisories to rural communities that were supported by local rural working groups. The GTPA continues to meet, and produce an agrometeorological monitoring and advisory bulletin every 10 days during the May-October rainy season (Carr and Onzere, 2018). In 2012, the National Meteorological Agency (Meteo Mali) was created from a department under the Ministry of Infrastructure and Transport, to be a financially semi-autonomous parastatal required and empowered to raise its own funds (Freudenberger et al., 2014). However, personnel and observing infrastructure constraints and poor internet connectivity have limited Meteo Mali's ability to provide commercial services at the level needed to mobilize sufficient private sector funding to cover costs, modernize facilities, and rebuild weather stations damaged by civil disturbances in 2012–2013 (Freudenberger et al., 2014; Montaud, 2019; Traoré et al., 2021). Mali's climate service landscape is changing with more private sector involvement (Ouédraogo, M. et al., 2020). Radio is the most widely used channel to communicate weather and climate information to smallholder farmers. Farmers' use of mobile phones to access information is increasing but limited by high illiteracy in smallholder communities (Dayamba et al., 2018).

Senegal

Senegal's agricultural climate service landscape reflects both the relatively strong technical capacity of its NMS, and the limited capacity to deliver climate services through public sector agricultural extension. Senegal's NMS, which has been part of the National Agency of Civil Aviation and Meteorology [*Agence Nationale de l'Aviation Civile et de la Météorologie* (ANACIM)] since 2011, provides one of the most advanced suites of online climate information products in West Africa. ANACIM has benefitted from recent investment in human and computing capacity by IRI, CCAFS and USAID. Similar to Mali, the mechanism of multi-disciplinary working groups [*Groupes de Travail Pluridisciplinaire* (GTP)] brings a range of relevant institutions to monitor climate conditions, translate weather and climate information into actionable advisories, and communicate the information with decision makers across sectors (Blundo-Canto et al., 2021). A national GTP was first established in 1984, and revived as part of Senegal's National Framework for Climate Services[3]. The national GTP has been replicated at a local scale in 29 departments beginning in 2012. The development of climate service radio programming through *Union des Radios Associatives et Communautaires du Sénégal* (URAC), an association of 114 community-based rural radio stations, with training and technical support from CCAFS, greatly expanded the accessibility and use of weather and climate information among smallholder farmers (Ouédraogo, I. et al., 2020). The development of public agricultural climate services faced two important challenges: weak public sector agricultural extension capacity, and a requirement that ANACIM raise part of its revenue from private sources. With support from the USAID-funded Climate Information Services for Increased Resilience and Productivity in Senegal (CINSERE) project, ANACIM and its partners responded to these challenges by developing a strategy that emphasizes PPPs and use of digital channels to deliver information and services to farmers (Ouedraogo et al., 2018; Blundo-Canto et al., 2021).

3 National Frameworks for Climate Services are described in Section Heterogeneous demand.

Zambia

The range of climate information products available and channels by which farmers can access them are quite limited in Zambia. However, policy changes and project investments are changing the agricultural climate service landscape. Zambia Meteorological Department (ZMD) moved from the Ministry of Transport and Communications to the Ministry of Green Economy and Environment. Zambia's Second National Agricultural Policy, and the Seventh National Development Plan aim to strengthen climate services and agricultural extension. ZMD collaborates with the Ministry of Agriculture to support the country's farmers with weather and seasonal forecasts. The large number (73) of languages used in Zambia is a major challenge to providing services to smallholder farmers. As in other SSA countries where NMS and agricultural extension face significant resource constraints, radio is the most important channel for providing information to farmers. ZMD currently lacks a functioning website, which limits visibility and accessibility of its information products. A few NGOs take the initiative to go to ZMD for information that they share with rural communities. Recent project-based investments have strengthened ZMD's automated weather station network and computing infrastructure, but human resources are still constraining. Zambia has an active technology sector, which is increasingly involved in developing mobile phone-based services for farmers.

Potential drivers of national agricultural climate services

In this section, we discuss the degree to which four key country-specific factors (demand, national policy, capacity to deliver information, and external actors) can account for differences that exist among the focus countries.

Heterogeneous demand

Climate service needs have been studied more for rainfed annual crops than for other agricultural systems. For these systems, the literature suggests that there are aspects of climate service needs that are heterogeneous even within communities, and aspects that are largely consistent across countries and agro-ecologies. Sociocultural norms that differentiate farming and decision-making roles and access to communication and financial assets based on gender, age, ethnicity or caste can lead to differences in the information that individuals can act on, the channels available to access information, and needs for training and support. Recognition that these needs can be quite heterogeneous is one of the drivers of the growing emphasis on engaging users in co-production of climate services (Vaughan and Dessai, 2014). On the other hand, the types of climate sensitive decisions that rainfed annual crop producers make, and the types and formats of weather and climate information that can support those decisions seem to be rather consistent among studies conducted across countries and contexts (Hansen et al., 2019b; Nkiaka et al., 2019; Born et al., 2021). This includes: seasonal precipitation forecast to inform farm land allocation, crop selection and input (e.g., seed, fertilizer) use; the timing of rainfall onset and dry spell risk to inform the timing of sowing, particularly in semi-arid climates; and weather forecasts to inform field operations such as weeding, pest management, supplementary irrigation and harvesting once the crop is established. Although differences in climate service needs have been linked with individual characteristics, they do not seem to result in discernible differences when aggregated to a national scale.

There is reason to expect climate information needs to differ between rainfed annual crop production, irrigated agriculture, perennial crops, and pastoralism systems. Climate information needs are different for irrigated and rainfed agriculture, in part because irrigation generally reduces the sensitivity of crops to rainfall variability. The need to manage scarce irrigation resources in a cost-effective manner creates a demand for additional information related to soil water balance, evapotranspiration, seasonal dam water level and crop water stress (Nyadzi et al., 2018). Perennial crops such as tea, coffee and fruit trees are quite different than annual crops in their management and hence their climate information requirements. Temperature is often a crucial variable for flowering and for the quality of production of commercially important perennial crops (Parker et al., 2020). For livestock, information needs focus on climate impacts on animal disease risks, and on availability of grazing, fodder and surface water resources—including distant locations where transhumance is part of climate risk management (Rasmussen et al., 2014).

The food and cash crop value chains that are important for smallholder livelihoods differ among the six focus countries (Figure 2). We would expect to see more products that are tailored to the most important value chains, including livestock in Ethiopia, Kenya and Mali; and irrigated annual crops—primarily rice—in Senegal and Mali. Since this is not the case, we conclude that the differences in agricultural climate service available among the focus countries have been driven by factors other than demand.

National policy

Agricultural climate services in SSA may be influenced by policies related to climate, agriculture, decentralization and public investment. Effective agricultural climate services require strong collaboration between the NMS and agricultural institutions, but these institutions fall under different policy frameworks that can have redundancies, contradictions or gaps.

Climate policy

Climate policies that influence NMS funding and mandates include national frameworks for climate services (NFCS) under the UN Global Framework for Climate Services (GFCS), and national adaptation plans under the United Nations Framework Convention on Climate Change (UNFCCC). The GFCS offers guidelines and technical support to develop NFCS that include multi-sector climate service policies and institutional arrangements, and priorities for investment. NFCS have been finalized in three focus countries (Ethiopia, Mali, and Senegal), and are under varying stages of development in the others. NFCS have formalized and strengthened coordination between NMS and government institutions that represent climate-sensitive sectors. However, as an NMS-led process, NFCS tend to give institutions in the climate-sensitive sectors, including Ministries of Agriculture, limited ownership and responsibility. In the two focus countries that have made the most progress mainstreaming climate services into agricultural extension, progress has been driven more by the government institutions responsible for agriculture (in Ethiopia) and disaster risk management (in Kenya). While Mali was the first of our focus countries to establish a NFCS, lack of clarity about the institutional framework, and resource constraints hamper its implementation.

Under the UNFCCC, National Adaptation Plans (NAPs) and the earlier National Adaptation Programs of Action (NAPAs) identify investment priorities for accessing international climate finance. Only two (Kenya and Ethiopia) of our 6 focus countries, and 8 out of the 46 countries in sub-Saharan Africa, have submitted NAPs at the time of writing. Both NAPs include strengthening NMS, and Kenya's aims to integrate indigenous knowledge into early warning systems. Ghana created a framework to guide development of their NAP, which prioritizes climate resilient development through community-based adaptation. The other focus countries (Zambia, Senegal, and Mali) submitted NAPAs that include early warning systems for rural areas.

Where NMS sit within the government may be both a driver and a reflection of the priority that national governments place on climate. Among our focus countries, the two NMS (Ethiopia and Kenya) that serve the broadest range of sectors and benefit from the strongest public sector support are embedded in ministries of environment. Those that are embedded in ministries responsible for transport (Senegal, Mali) or communication (Ghana) either provide much more limited services for agriculture, or seek to generate revenue through commercial services. It remains to be seen how a recent move from the ministry of Transport and Communications to Green Economy and Environment affects public support for Zambia's NMS.

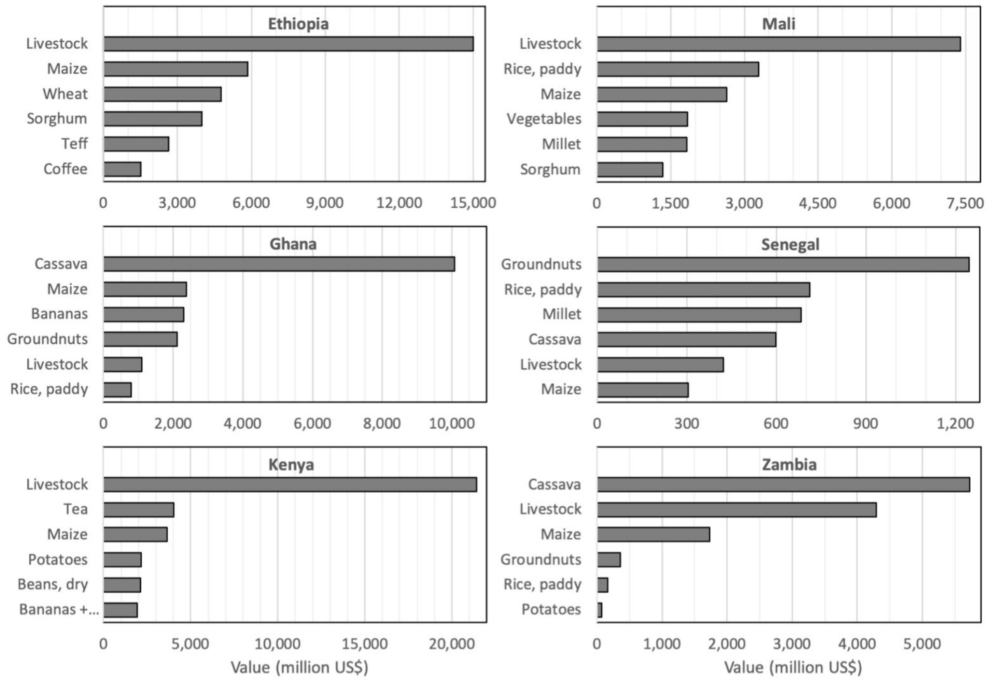

FIGURE 2
Top six agricultural value chains in each AICCRA country, based on value, 2016–2019 average. Source: FAOSTAT.

Agriculture policy

Although resilience to climate variability is one of the core commitments of the African Union's CAADP, the attention that national agricultural policies give to climate resilience is quite variable. The Senegalese Program to Accelerate Agriculture [in French, *Programme d'Acceleration de la Cadence de l'Agriculture Senegalaise* (PRACAS)] aims to increase the resilience of the vulnerable populations through programs such as crop diversification. One of the 9 flagships of Kenya's National Agriculture Investment Plan (2019–2024) aims to enhance household resilience while reducing food insecurity. Zambia and Ghana incorporate climate resilient agricultural production methods in their agricultural policy but neither explicitly includes resilience in their framework. Ethiopian agricultural policy briefly mentions resilient farming systems, although resilience appears not to be an explicit objective. Mali's Agricultural Development Policy [in French, *Politique de Développement Agricole du Mali* (PDA)] includes climate change adaptation to strengthen the capacity of vulnerable populations and protect natural resources, but does not mention climate services.

Investment

In Africa, the level of public investment in NMS and in agricultural extension has a strong influence on the climate services that are available to farmers. Differences in public investment reflect differences in size of the national economies, the priority given to climate and agriculture in the national policies described above, and lingering impacts of competing external efforts both to reduce and to increase investment in public services. While country-level data on investment in NMS and agricultural extension are generally not available, public investment in agriculture, forestry and fisheries provides a glimpse of the investment environments in which services operate (Figure 3). Relatively high government spending by Ethiopia and Kenya reflects the size of their economies. This likely benefits the NMS more than their agricultural extension services as the cost of generating climate information is less sensitive to the size of the population served than the cost of delivering services to farmers. Investment per capita is relatively high in Ghana, Kenya, and Mali; whereas Mali invests the most as a percentage of GDP. Zambia stands out for its relatively low investment in agriculture-related sectors.

Public investment in agricultural climate services has been influenced by competing external efforts both to decrease and to increase government investment in services. For roughly two decades since the late 1980s, development lenders such as World Bank and International Monetary Fund promoted structural adjustment programs that encouraged developing countries to reduce government spending, and privatize or downsize public services. NMS and agricultural extension services responded to reduced public investment in several ways, including: scaling back services, generating revenue through specialized fee-based services, subsidizing services with project funds, and in the

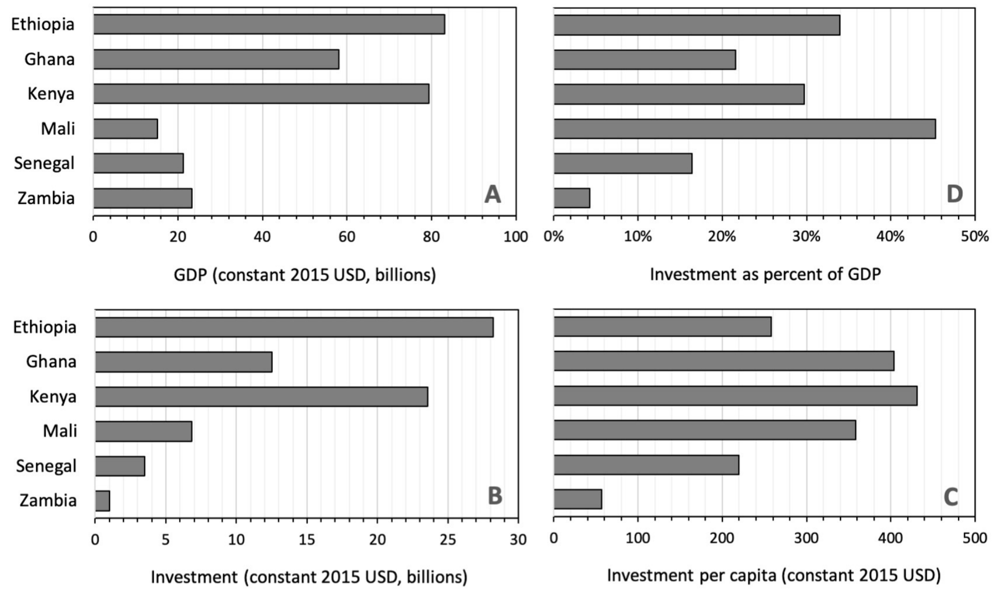

FIGURE 3
Gross domestic product (GDP) **(A)** country investment in agriculture, forestry and fishing **(B)**, investment per-capita **(C)** and investment as percent of GDP **(D)**; constant 2015 USD, 2016–2020 average. Source: World Bank World Development Indicators database, and FAOSTAT.

case of NMS, treating data as a commodity rather than a public good. Efforts such as the Millennium Development Goals (MDG) and subsequent Sustainable Development Goals (SDG) at a global level, and in Africa the Comprehensive African Agriculture Development Program (CAADP), have reversed the decline in investment in agriculture in many African countries, including all AICCRA countries except Zambia (Figure 4). Africa-wide efforts to increase public investment in climate services, including a 2019 declaration by AMCOMET and the Climate Research for Development (CR4D) initiative, have been more recent and, so far, less successful.

Decentralization

Most governments in SSA have increasingly devolved decision making, finance and services from national to local levels as a way to achieve development and democratization goals. Among our focus countries, Kenya has implemented the most aggressive decentralization reforms. Effective decentralization of both climate and agricultural extension services has enabled a degree of integration of these services in Kenya at the county level. While the other five countries have decentralization policies, they have not led to similar decentralization of climate services. Ethiopia's eleven regional states have a high degree of autonomy, and its NMS, like Kenya's, has a network of strong Regional Meteorological Centers distributed across the country. Yet Ethiopia's climate services remain largely centralized, and its sub-national centers play a very limited role in tailoring and delivering climate services for their respective regions. Subnational NMS offices in countries such as Zambia and Mali are used primarily to collect data rather than provide services. Decentralizing services involves trade-offs. While divesting responsibility from the national to local level can give agricultural decision makers a greater voice in the co-production of climate services, spreading the scarce human resources of an under-funded NMS could reduce the quality and coherence of those services.

"Last mile" capacity

In many countries in SSA, smallholder farmers and pastoralists represent the majority of the work force. Their numbers and remoteness intensify the challenge of delivering effective agricultural climate services. These challenges are particularly important when services aim to go beyond information dissemination, to build capacity to understand and use probabilistic climate information and to participate in the co-production of improved services. We consider differences among countries in capacity to reach their rural populations through institutional and ICT channels.

Agricultural extension capacity

Agricultural extension services provided by public sector or non-state actors are, in principle, the main institutional mechanism for supporting farming populations with information, guidance and training. Although the strength of agricultural extension services influences their potential to support farmers with climate services, and varies considerably

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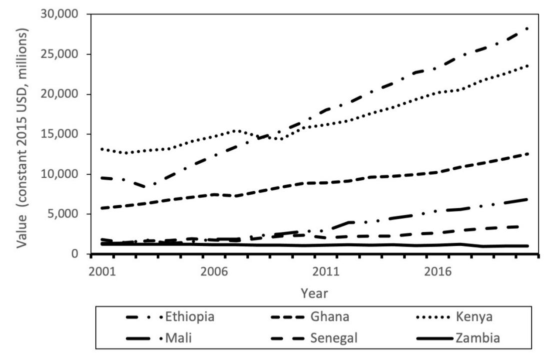

FIGURE 4
Annual country investment in agriculture, forestry and fishing, 2001–2020, constant 2015 USD. Source: FAOSTAT.

across SSA, this potential has not been fully exploited in any of the focus countries.

Table 4 summarizes key features of the agricultural extension systems in the focus countries. With the exceptions of Mali and Senegal, Ministries of Agriculture are responsible for providing extension services. In Mali, the Ministry of Agriculture coordinates extension activities that are spread across ministries and agencies responsible for crops, livestock, veterinary services, forestry, regions, irrigation and aquaculture (DLEC, 2018). In Senegal, the mandated institution [National Agency for Rural Advisory Services (ANCAR)] is a parastatal controlled by the national government (Franzel et al., 2018). Agricultural extension strategy varies by country, and emphasizes demand-driven participatory approaches (Ethiopia, Kenya, Senegal), market orientation (Ghana), decentralization (Kenya, Ghana) and pluralism (Ghana, Kenya, Senegal, Mali, Zambia) (Moore et al., 2015; Muatha et al., 2017; DLEC, 2018; Franzel et al., 2018). Responsibility for extension services has devolved to local governments in Kenya and Ghana (Moore et al., 2015; Muatha et al., 2017; Quaye et al., 2017; DLEC, 2018; Anang et al., 2020). Ethiopia's digital agriculture strategy seeks to use digital decision support tools and communication channels to enhance the capacity and reach of its public extension staff. Kenya's digital strategy promotes wide use of digital tools and platforms by public and fee-based private sector extension services in Kenya (Gichamba et al., 2017).

Ethiopia has Africa's largest public agricultural extension system, with about 72,000 staff based in 15,000 Farmer Training Centers as of 2017 (DLEC, 2018; Davis, 2020). The remaining five focus countries support pluralistic extension strategies that leverage and coordinate non-state agricultural advisory services providers. These non-state extension and advisory service providers include producer associations and cooperatives (Kenya, Ghana, Mali, Senegal, Zambia), development and faith-based NGOs supported by donor project funding (Kenya, Ghana, Mali, Senegal), agribusiness enterprises (Kenya, Mali, Senegal, Zambia), bundled contract farming services (Ghana), and in Mali two parastatals (Malian Company for Textile Development, and Niger Office) that provide services for cotton and rice producers (Moore et al., 2015; Muatha et al., 2017; Danso-Abbeam et al., 2018; DLEC, 2018; Poku et al., 2018; Binpori et al., 2021). Among these countries, public extension investment and capacity are particularly limited in Zambia and Senegal, and dependent on donor project funding in 2010–2017 in Mali.

ICT development

The rapid expansion of ICT infrastructure and mobile phone use among rural populations has prompted rapid development of digital strategies (e.g., mobile phone text and voice push messages, IVR, call centers, web-based and smartphone apps) for delivering services to farmers. However, countries in SSA differ substantially in the state of ICT development, and hence their capacity to develop digital agricultural climate and advisory services. Figure 5 shows the Mobile Connectivity Index (MCI) and its four enabler component scores, relative to 40 sub-Saharan Africa countries, published by the *Groupe Speciale Mobile Association* (GSMA). Based on aggregate MCI, Ghana and Kenya are relatively well positioned to exploit digital innovation and communication channels to provide services to their rural populations. Mali, Zambia and Ethiopia are relatively weak and therefore expected to face significant constraints in the near term. Senegal falls between the strong and weak countries in our study but above the median across SSA. Among the three countries (Mali, Zambia, and Ethiopia) with lowest overall scores, consumer readiness (based on mobile phone ownership, skills and gender equality) is relatively strong in Zambia, and services are relatively affordable (based on tariffs, handset price, taxation, inequality) in Mali and Ethiopia. In countries, such as Mali, low access to electricity (12% of rural population) and persistent illiteracy remain impediments to scaling digital services (KIT, 2020). Senegal's intermediate ranking reflects a combination of strength in network infrastructure and affordability, and gaps in content and services. Among the countries with low MCI scores, Ethiopia's strong agricultural extension service compensates for ICT capacity constraints in Ethiopia, but Mali and Zambia face major constraints to delivering climate services to farmers through digital and institutional channels.

The external climate services community

National climate services in SSA interact with an external climate services community that includes researchers who work across the supply and demand sides of climate services, donors who fund a dynamic set of time-bound implementation and capacity development projects, a growing set of development organizations responding to increased donor support, and

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TABLE 4 Key features of agricultural extension services in focus countries.

Country	Public extension personnel	Key/notable features
Ethiopia	∼70,000	Large public investment. Large staff work through farmer training centers. Partially decentralized. Technology transfer strategy, blanket recommendations. Uses broadcast media, trainings, meetings and demonstrations. Expanding use of digital technologies to reach farmers and support field staff.
Ghana	∼3,500	Decentralized. Dependent on donor funding. Research-extension-farmer liaison committees. Emphasizes market orientation. Proliferation of private sector extension services.
Kenya	∼5,470	Decentralized. Strongly pluralistic, including commercial advisory services. Participatory extension strategy. Farmer-to-farmer, broadcast media and digital delivery channels.
Mali	839	Relatively weak public extension. Dependent on donor funding. Technology transfer strategy. Private advisory services from input suppliers. Radio the most important communication channel. Services are accessible to roughly 20% of farmers (KIT, 2020).
Senegal	156	Limited resourcing of public extension system. Led by a parastatal that promotes participatory approaches, leverages and coordinates producer organizations and NGOs.
Zambia	742	Hierarchical decentralized public extension. Resource constrained. Pluralistic including NGOs and private sector. Radio the most important communication channel.

private sector weather and climate information providers based in the Global North.

International coordination and support for NMS. Major external initiatives are raising NMA capacity across countries. For example, the Africa Hydromet Program, led by World Bank in partnership with WMO and six other development funders, is supporting 15 NMS and four RCCs to modernize their infrastructure and services[4]. The UK-funded Weather and Climate Information Services for Africa (WISER) program[5] has strengthened capacity across the generation, translation, communication and use of climate services, at regional and country levels, primarily in Eastern Africa. With technical support through the IRI's ENACTS initiative, 14 African NMS, including the AICCRA countries except for Mali, now provide historical (e.g., seasonality, variability, and trends) and monitored climate analysis that are tailored to agricultural needs and provided at the local spatial scale of farm decision making (Nsengiyumva et al., 2021). These products are built on high-quality gridded (∼4-km) historical daily data sets generated by merging station records with satellite rainfall estimates and climate model reanalysis temperature products; and made available spatially and for any selected location through online Maprooms (Nsengiyumva et al., 2021). Ethiopia, Kenya, and Zambia are among a smaller set of African countries that have introduced objective Next Generation seasonal forecasts, downscaled onto the same gridded data and presented in a format that addresses the main weaknesses of conventional seasonal forecasts. Since Maproom tools developed in response to demand in one country can be transferred to other countries easily and at relatively low cost, the ENACTS approach is reducing differences among NMS in the information they provide.

NMS across Africa benefit from the technical support, coordination and advocacy roles of the WMO; Regional Climate Outlook Forums (RCOFs); services and training provided by Regional Climate Centers (RCCs); and political cooperation and advocacy through the African Ministerial Conference on Meteorology (AMCOMET). These regional and global processes have a positive influence on the capacity of NMS across SSA, and on the consistency of the climate services they provide. However, as top-down political processes they can be slow to respond to local needs. For example, through much of their history, African RCOFs reinforced seasonal forecast conventions and restrictive data policies that limited the usefulness of climate services for agricultural decision makers (Vogel and O'Brien, 2006; Daly and Dessai, 2018). This changed recently in Eastern Africa, where the Greater Horn of Africa Regional Climate Outlook Forum (GHACOF) and its host RCC (ICPAC) have introduced objective seasonal forecast methods and improved ways to present forecasts in response to WMO guidelines and a series of capacity development projects.

Divergent influence of externally funded projects. In contrast to the coordinating role that WMO, RCCs, and AMCOMET play, the differing priorities, approaches and experience that external climate service implementers and funders bring to projects have contributed to the diversity of national agricultural climate service development trajectories. Large development and adaptation projects have a great deal of influence on the agendas and strategies of developing country institutions that are dependent on donor funding. Short-term projects, led and funded by different institutions, often develop new tools and approaches instead of building on existing knowledge and coordinating with other climate service actors. Factors that contribute to this problem include the growing

4 https://www.gfdrr.org/en/feature-story/modernizing-meteorological-services-build-climate-resilience-across-africa.

5 https://www.metoffice.gov.uk/about-us/what/working-with-other-organisations/international/projects/wise.

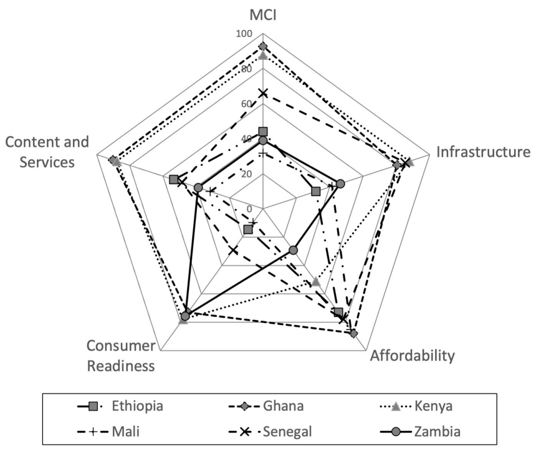

FIGURE 5
GSMA 2020 Mobile Connectivity Index (MCI) and enabler component scores, percentile rank among 40 sub-Saharan Africa countries. Source: https://www.mobileconnectivityindex.com.

number of new development organizations that are moving into climate services with little relevant experience, and an absence of agreed good practice standards and coordination mechanisms. Consequences include inefficiencies, gaps and redundancies within countries; and divergent climate service trajectories among countries and sub-regions.

Project lifecycles tend to work against the goal of building sustainable capacity. Breaks between externally funded projects can disrupt public services that depend on project funding (Jones et al., 2016), interrupt subsidies that incentivize private sector investment (Antwi-Agyei et al., 2021), and impede accumulation of knowledge by favoring *ad-hoc* needs assessments over sustained user engagement in the co-design of services (Vogel et al., 2019). Funder requirements to demonstrate scaling or impact objectives can lead to short-term strategies that sacrifice sustainability, such as prioritizing the weather time scale over more complex climate information, disseminating information through broadcast media or mobile phone push messages without investing in farmers' capacity to use information appropriately, and funding private weather information providers from the Global North instead of building NMS capacity (Dupar et al., 2021). Several climate service funders, such as the WISER program, are aware and actively seeking solutions to these sustainability challenges.

Discussion: Implications for strengthening services

In this section, we discuss several approaches for strengthening agricultural climate services. We consider how existing differences in national agricultural climate service landscapes and their drivers can be expected to interact with these proposed interventions to enable or constrain advances in the effectiveness, scalability and sustainability of agricultural climate services in our focus countries in the near future.

Leverage farmer demand to drive scaling and impact

The prospect of scaling up agricultural climate services in a sustainable manner is greatest when services are driven by demand. Although the climate services community has long recognized that engaging users in co-production can improve the salience and legitimacy of services (Kirchhoff et al., 2015; Buizer et al., 2016; Bednarek et al., 2018), the development of agricultural climate services across SSA appears to have been driven more by external project initiatives and government policies than by user demand. A 2006 multi-stakeholder, cross-sectoral assessment of the state of climate services across Africa suggests an explanation: If climate information is poorly aligned with their needs, decision makers have difficulty acting on existing information, and cannot effectively express demand for improved information without understanding what can feasibly be provided. On the other hand, without clear, effective demand from farmers or other decision makers, it is difficult for under-funded NMS to justify efforts and mobilize additional resources to improve the information they provide. If inadequate climate information and ineffective farmer demand reinforce each other, then strengthening both NMS capacity to supply actionable information, and farmers' capacity to use available information and engage NMS in co-production, can help enable farmer demand to drive improved services.

The size and remoteness of rural populations, differences in education level and political power, and cultural norms make it challenging to bring farmers' voice into services. These barriers can be reduced by building farmers' capacity, and through institutional mechanisms that amplify farmers' voice. Farmers typically need training to understand and act appropriately on probabilistic climate information before they can engage effectively in co-production of improved information. Institutional mechanisms can amplify farmers' voice in climate services. Since remoteness provides an obstacle from engaging national institutions, decentralized services, such as Kenya's county-level climate services, have an advantage in engaging farmer representatives and service providers in co-production. A boundary-spanning institution or network that has sufficient expertise and connections with both the climate and user community can help broker communication and negotiate solutions needed to align services to decision-maker needs (McNie, 2012; Lemos et al., 2014; Buizer et al., 2016; Bednarek et al., 2018). Successful examples of boundary spanning in our focus countries include the Adaptation Consortium that facilitates development of county climate services in Kenya, and local multidisciplinary working groups (GTP) in Senegal. While producer associations and development NGOs may be effective at representing farmers' needs, they often lack the climate expertise needed to negotiate solutions with NMS.

In countries where the gap between farmers' needs and available information is large, it is difficult for farmers to express demand for valuable new information that they've had no exposure to. Reducing the gap by supporting NMS to improve the information they provide therefore offers a relatively straightforward way to stimulate demand. Until recently, widespread gaps between available information and known decision maker needs have limited the usefulness of climate services for rainfed agriculture across Africa. Constraints include seasonal forecast conventions that limit their usability for local decision making, lack of information about the timing and duration of the rainfed growing season, and unavailability of historical data and analyses (Hansen et al., 2019b). In countries where NMS are addressing these longstanding gaps in climate services for rainfed crops, services can be further strengthened by prioritizing the additional climate information needs of livestock, irrigated crops and high-value perennials in countries where these value chains are important; and by focusing the intensive interactions that co-production requires on a smaller set of context-specific priority needs.

Exploit digital innovation within a diverse delivery strategy

Within the growing private-led farmer advisory service sector in Africa, and among large agricultural adaptation initiatives such as the CCAFS transformation initiative (Steiner et al., 2020) and GCA digital climate advisory service initiative (Ferdinand et al., 2021) cited in the Introduction, there is a strong focus on using mobile phones and digital innovation to bundle weather and climate information with agricultural advisories and to deliver services to farmers. The growing focus on digital delivery of services is driven in part by the promise of extending access to larger numbers of farmers.

Digital channels can improve reach and effectiveness when used strategically to strengthen and complement other channels, but they leave important gaps in communication processes and capacity if used alone, particularly for decision making at a climate time scale. The distinction between weather (i.e., the state of the atmosphere at a particular time) and climate (the statistics of weather over periods of months or longer) has important implications for communication strategy (Marx et al., 2007; Hansen et al., 2019b). Weather information (e.g., daily observations, forecasts out to about 10 days) is needed frequently. Because people experience weather daily, they quickly learn to assess the accuracy of this information and factor it into decision-making. Climate information (e.g., historical analyses of seasonality, variability and trends; season forecasts) is more abstract and inherently probabilistic. Because climate information is consulted at most a few times each year, farmers must depend on statistical descriptions instead of personal experience to assess its accuracy, and require training to interpret it and act appropriately. Mobile phone and broadcast media channels work well for daily weather forecasts and the routine agricultural decisions they inform, but are less suited for historical and forecast information at a climate time scale. In-person processes that employ visual presentation and participatory activities have proven effective for communicating probabilistic climate information and for supporting farmers to use it. While this is not possible through mobile phone text or voice messages alone, digital channels can strengthen face-to-face participatory processes and institutional channels (Duncombe, 2018; Fabregas et al., 2019; Tsan et al., 2019). The Ethiopia Ministry of Agriculture strategy, for example, treats digital tools and platforms as a way to strengthen the capacity of field staff to provide climate-informed agricultural advisories to the farmers that they advise. A diverse communication strategy also reduces the risk that services exclude disadvantaged farmers and exacerbate rural inequality. Although network coverage is expanding across SSA, gaps in coverage still exclude farmers in many remote, marginal regions. Fee-based services risk excluding a large proportion of farmers who lack the willingness or ability to pay (Table 5), particularly subsistence-oriented farmers, and women farmers in patriarchal cultures who lack control over household finances, potentially exacerbating existing inequalities.

Balance public and private sector comparative advantage

While most countries mandate public institutions to provide climate and agricultural advisory services, the private sector is playing a growing role across Africa in generating weather and climate information, translating it into advisories, and delivering services to farmers. Public and private organizations have differing strengths and limitations that vary by country, yet a few generalizations hold across most countries.

Information has the characteristics of a public good (Freebairn and Zillman, 2002), and in most countries, public organizations are best positioned to produce the data and information that underpin services for farmers. Although the gap between farmers' needs and the information available through their NMS appeared to be the most widespread obstacle to supporting African farmers with climate services, this is changing rapidly as capacity development projects are enabling a growing set of NMS to greatly improve the quality, diversity and relevance of their information products. Subsidizing private companies from the Global North to provide weather information to farmers in Africa may appeal to the immediate

TABLE 5 Published studies of the proportion of farmers willing to pay for weather and climate information.

References	Country	Product	Willing to pay (%)	Sample size
Amegnaglo et al. (2017)	Benin	Seasonal forecasts	81	354
Ouédraogo et al. (2018)	Burkina Faso	Seasonal forecast	53	169
		10-daily information	33	
		Daily forecast	53	
		Agro-advisories	33	
Zongo et al. (2015)	Burkina Faso	Seasonal forecasts	64	629
Antwi-Agyei et al. (2021)	Ghana	Various	43	193
		Seasonal forecast	21	
		Daily forecast	24	

scaling goals of donors, but can work against sustainability and effectiveness. In cases we are aware of in Kenya, Ghana, Mali, and Senegal, evidence is lacking to support claims that these external companies offer higher quality information than the NMS in the countries where they operate. African NMS typically steward orders of magnitude more station data than are available to external organizations, and are therefore able to provide higher-quality gridded historical data and localized analyses (Dinku et al., 2014, 2018). The provision of redundant and conflicting weather forecasts by a donor-funded European company led to tensions with the NMS of Mali (Kirbyshire and Wilkinson, 2019) and Senegal; and in the case of Senegal, problems with their accuracy undermined the credibility of the NMS among farmers who were not aware of their source. The recently announced closing of a U.S. company that supplied weather information for farmers in several African countries, with international donor funding, highlights the importance of investing in public information providers to ensure quality, accountability and sustainability.

Because the private sector typically faces fewer obstacles to innovating, it often has a comparative advantage in aspects of service delivery such as developing user-friendly digital tools, bundling new information into existing services for farmers, and developing specialized advisories for high-value agricultural commodities. Private-sector farmer advisory services that exploit mobile phone delivery channels are expanding accessibility and adding value to weather information. However, mobile phone channels that work well for routine information and advisories on a weather time scale often leave a gap in farmers' capacity to understand and act on probabilistic information at a climate time scale. Participatory communication and training processes, facilitated by public extension services where effective, or by NGOs and producer associations where they fill a gap in public extension services, are more effective at building farmers' capacity to understand and act on probabilistic information at a climate time scale.

In the case of translating weather and climate information into useful agricultural management advisories, the relative capacity of public and private sector actors likely varies by country and context. Most of our focus countries have reasonably strong public agricultural research organizations. Private companies that issue weather-based farm management advisories could help scale up or complement the advisories that come from public agricultural extension systems if their efforts are coordinated.

The importance of considering public and private sector comparative advantage extends to funding. Inadequate public investment in NMS is a bottleneck to providing useful agricultural climate services, especially in countries like Senegal, Mali, Ghana and Zambia where NMS fall under ministries associated with commercial sectors such as transportation or communication. Concern about the public funding gap and dependence on short-term project funding has prompted several efforts to develop fee- or subscription-based business models. So far, there appear to be few successful cases where user-pays business models have generated revenue to fill NMS public funding gaps and support significant improvements to the services they provide. The growing body of evidence of the productivity and livelihood impacts of well-designed agricultural climate services offers an economic argument for national governments to increase public investment in appropriate climate service public goods.

Embed climate services in agricultural extension

Climate and agricultural advisory information are synergistic; and integrating climate services into agricultural extension services can be expected to increase the value of both to farmers. Climate information can be used to tailor agricultural management advisories to local climate conditions and anticipated climate fluctuations. Agricultural extension services can add value to weather and climate information by translating it into actionable farm management options. Furthermore, agricultural extension services provided by public sector or non-state actors typically have much greater capacity than NMS to reach farming communities. While the mechanism for embedding climate services into agricultural extension are likely to vary by country, it would generally require changing national policy to expand the mandate of agricultural extension; and to enable co-ownership, define shared responsibility and accountability, and support information exchange between the NMS and Ministry of Agriculture. It would also require training to build competencies of agricultural extension personnel related to climate literacy, available climate information products and tools, the implications of climate information for farmers' management decisions and existing advisories, and good practice in supporting farmers with climate-related information.

While we see evidence of progress in counties in Kenya and at the national level in Ethiopia, the potential for the synergies between climate and advisory services to improve the effectiveness of both remains largely unexploited in our focus countries and across SSA. Obstacles include institutional and policy barriers that separate climate and agricultural institutions, and in some countries the limited capacity of agricultural extension systems or the NMS. The potential benefits are greatest in countries, such as Ethiopia, that have maintained strong public investment in agricultural extension. Ethiopia's Ministry of Agriculture and its research institutions have already taken initiative to bring weather and climate services into agricultural extension. Even countries with relatively weak public agricultural extension services, such as Zambia, Mali and Senegal, use public resources to support and coordinate pluralistic farmer advisory services through combinations of NGOs, producer associations and private companies. Private sector services that bundle weather and climate information with farmer advisories and production inputs are relatively mature in Kenya, emerging in Ghana and Senegal, and at early stages of development in Mali, Zambia, and Ethiopia.

Conclusions

The diverse approaches that climate and development organizations bring interact with national context to influence the effectiveness, scale and sustainability of agricultural climate services, in ways that are poorly understood and difficult to analyze and anticipate. To shed light on this challenge, this paper highlights the importance of considering these context-specific interactions in efforts to strengthen the contribution of climate services to agriculture.

Available evidence suggests that the substantial differences in the state of agricultural climate services that exist among these countries have been driven largely by national policies and priorities, ICT and institutional capacity to deliver services, and the influence of the international climate service community, but not by responsiveness to agricultural sector demands. Two closely related developments—increasing focus on mobile phone and related digital channels to deliver services, and increasing participation of private sector service providers—are opening new opportunities, and also carry significant risks that seem to be greater in countries where government policy and financial commitments are weaker.

We discussed four key opportunities to strengthen the contribution of climate services to agriculture and farmer welfare that are relevant across countries in SSA, but that need to be adapted to differing country contexts. The first is to leverage farmer demand to drive scaling and impact, by building farmers' capacity to understand and use climate information effectively and engage with the network of service providers in co-production, and by further reducing gaps between known farmer needs and the information products that NMS provide. Second, strategically combine digital and institutional climate service communication processes to exploit their complementarities and address the diverse communication needs of farming populations. Third, work to engage and support public- and private-sector actors for the roles for which they have the comparative advantage. In most countries in SSA, including our focus countries, this calls for maintaining or bolstering investment and an enabling environment for public goods that include generating relevant climate-related information, and building farmers' capacity to use climate information and drive co-production where the private sector is not doing so. Finally, we see integrating climate services into national agricultural extension systems (public, NGO, and private) and policy as a particularly promising opportunity to increase the value of both. Awareness of existing agricultural climate service landscapes and the forces that have shaped them; and the potential trade-offs that exist among effectiveness, scalability and sustainability goals; can help organizations that seek to strengthen climate services to minimize risks and unintended trade-offs as they adapt these strategies to particular country contexts.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author/s.

Author contributions

JH led development of the paper and overall framing, and coordinated and integrated coauthor input. LB coordinated search for published literature and secondary data. ED-Y (Mali), CM (Kenya), MD, OT (Ghana), AW (Senegal), and TD (Zambia and Ethiopia) provided country-specific content. DS, RZ, SZ, AG, TD, and AW contributed to overall framing and edits to improve clarity and completeness throughout the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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