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Transforming Agrifood Systems in West and Central Africa Initiative

(TAFS-WCA)

Mapping Climate and Agronomic Digital Advisory Services Landscape in West and Central Africa (WCA)

Alliance of Bioversity International & CIAT

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Background

The net importer status of African countries, in the era of ongoing global conflicts, food crisis, and climate change, is something to worry about for their consistently increasing population. Food production in most of these countries remain below-average. Main constraints to food production include (1) unavailability of quality seed, fertilizer, water, agricultural machinery, and credit during the crop growing period; (2) extremely fragmented land holdings, which pose challenge to farm mechanization; and (3) farming under rainfed conditions (Nyasimi et al., 2016; FAO, 2022; Kropff et al., 2021). In Rwanda, the average land size per farm household is 0.76 hectares and 80% of farms are less than 1 hectare (The World Bank Group, 2021). Other constraints are: (1) inadequate disease control and surveillance system (Nel et al., 2019); (2) climatic and environmental constraints; (3) poor access to markets due to poor road infrastructure and insecurity (World Economic Forum, 2020); (4) limited availability of storage and processing facilities; (5) high levels of rural outmigration; and (6) price fluctuation (Daum et al., 2021; Downie, 2017). These problems are predominant among the smallholder farmers.

Productivity of food systems can be increased in a sustainable manner by making it resilient to the shocks of climate variability. This involves two steps: (1) growing crop under optimal management conditions; followed by (2) adoption of agronomic and cultural practices during crop growing season to minimise the impact of any biotic (infestation of insect-pest/weed, infection by a plant pathogen etc.) or abiotic stress (such as, extreme weather-related events). Crops when grown under optimal management conditions result in good yield and ensure food security of the households. In order to grow crops under optimal management conditions with maximum efficiency, a farmer needs to know the (1) crops and varieties suitable during the season considering the anticipated climate forecast; (2) the optimal seed rate and spacing and seeding depth; (3) critical crop growth stages when irrigation is required; (4) fertiliser scheduling (name, dose, time, method); (5) plant protection measures for common pests & diseases, and other market related information. Agro advisories encompass all these information at one place along with the interpretation of weather forecast. It has proved to be a useful tool for effective decision-making among the farming community.

Given the importance of the agricultural sector in the national economy and the increasing challenges faced by the producers, several international organizations have been working in partnership with the local government, telephone companies, NGOs to develop digital technologies to provide agronomic and climate advisory services to producers in various value chains. During the past decade, a range of digital tools were developed to assist and improve the extension services by designing interventions tailored to the needs of different categories of farmers. For example, fertilizer recommendations, package of practices, climate advisory services, pest and disease surveillance, providing tips on control, prevention and other agronomic management practices, etc. are being made available through various digital platforms. The state of development of infrastructure and other requirements for the successful implementation of digital agricultural services, however, is not the same across Africa.

This synthesis report, therefore, summarizes the socio-economic conditions of six countries in west and central Africa, the state of agriculture, the infrastructure (if any), existing digital agricultural services, and the tools available for improving access to financial and insurance services. Furthermore, efforts were made to identify the challenges in implementing digital agricultural services in the region, while also examining key aspects such as user research, the inclusivity of target users in decision-making, and data harmonization and management.

These information are essential for the identification of existing gaps and the potentials for successful implementation of these services, as well as studying their impact on the farming community and the food security in these countries.

MATERIAL & METHODOLOGY

Geographic Scope

This synthesis report has been generated based on the work carried out in six countries of west and central Africa (Figure 1) during 2021-22. The countries under study were Burundi, Côte d’Ivoire (CIV), Democratic Republic of Congo (DRC), Ghana, Nigeria, and Rwanda.

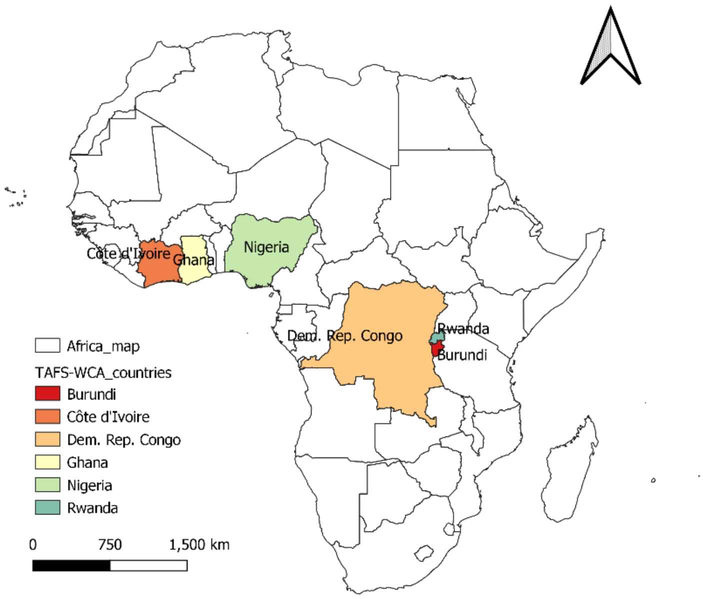


FIGURE 1. Administrative boundary of countries selected for mapping in WCA.

Socio-economic conditions

The countries selected for this study are home to millions of people, with Nigeria being the most populated country (Statista, 2023). Countries such as Rwanda and Burundi, although they are relatively smaller in area, inhabit over one billion population (Table 1). The income level of these countries is not good: it ranged from *low-income* to *low-to-middle* income level. Majority of the inhabitants live in rural areas. Burundi and Rwanda are largely rural countries, where more than 80% of the population lives in rural areas, which explains their limited access to electricity, sanitation, and good quality drinking water. For a big country like DRC, with only 15% of the agricultural land (World Bank, 2021), and where only 10% of this is being currently used (ITA, 2022), it is a big challenge to reach out all of its rural population in order to alleviate malnutrition and poverty. The percentage of population living below the poverty line (BPL) was still very high in most of these countries. Despite of the progress made in economic growth in these countries, the food security situation has worsened over the last decade. The number of people suffering from malnutrition has increased, however, the proportion varies in different countries (FAO, 2022). Based on Global Hunger Index (GHI) 2023, the hunger situation varies: it is *moderate* in Ghana; *serious* in Cote d'Ivore, Nigeria and Rwanda; whereas it is *alarming* in Burundi and DRC (Table 1).

TABLE 1. STATUS OF SOCIO-ECONOMIC VARIABLES IN DIFFERENT COUNTRIES

Country	**Rwanda**	**Côte d'Ivoire**	**Burundi**	**Nigeria**	**DRC**	**Ghana**
Socio-economic variables						
Region	East	West	Central	West	Central	West
Income level	low	Low - middle	low	Low-middle	Low	Low-middle
BPL population	52%	39.5 %	72.90%	31% (72 % farmers)	72%	23.40%
Population (million)	13.2	27	12.5	213.4	95.9	31.7
Access to drinking water	60%	76.6	83% in urban areas (60% rural)	68	52	96.4 % in urban areas (74.4%-rural)
Contribution (%) of agriculture in GDP	27	20	27.57	24.4 %	19.40	18.78
Contribution to employment (%)	56% (66.6% rural pop)	48%	NA	39 % (55% among rural pop)	60%	42%
Rural population (% of total)	83.00	47.80	86.00	48.00	54.36	42.00
Arable land (% of land area)	51.4	11	49.5	40.5	6	20.7
Agricultural land (% of land area)	81.3	73.9	81.9	75.4	15	55.4
Forest area (% of land area)	11.2	8.6	10.9	23.6	55.2	35.1
Food-security situation over the last decade						
Status of country	Importer	Importer	NA	Importer	Importer	Importer
Malnutrition rate (% of children under 5 years)	35%	NA	52%	5 to 30%**	40%	19 % (33% in northern region)
Rank of countries ***	96	86	NA	109	122	62
Level of hunger based on GHI	Serious	Serious	Alarming	Serious	Alarming	Moderate

* Compiled by authors from different sources

** moderate (severe) food insecurity represents 53% (26%) of the population in Nigeria

*** Rank of countries in terms of Global Hunger Index (GHI) out of 125 countries

Agriculture stands as one of the main sectors of economic importance for these countries, with a contribution ranging from ~ 18 to 28 % to the country's GDP (Table 1). In the past decade however, with the increasing contribution of industry and service sector, its contribution to the total GDP has fallen sharply. The contribution of agriculture to GDP was highest in Burundi, where cash crops (such as coffee, cotton, tea, and palm oil), accounts for about 90% of the country's export. Major food crops grown are listed in Table 2. Area under cultivation has increased in most of these countries. However, this has been achieved by extensive deforestation, which resulted in sharp decline in the total forest area. Deforestation was relatively higher in Cote d'Ivoire and Ghana.

Climate

Climate variables shows great heterogeneity at both spatial and temporal scales. The temporal distribution of rainy season is unimodal in Ghana, Nigeria, and Cote d'Ivoire, whereas it is bimodal in Burundi, Rwanda, and Democratic Republic of Congo (Figure 2). In west-African countries, rainy season continues from April to November, and dry season otherwise. In contrast, Burundi, Rwanda, and DRC have four climatic seasons: *long rainy season* (from March to May); *short rainy season* (from sept to November); *long dry season* (from June to august); and *short dry season* from December to February (World Bank Report, 2021). With regard to the mean monthly surface air-temperature, little fluctuation is observed in Rwanda, Burundi, and DRC during different months of the year. This suggests that the weather is same year around. However, these curves are wavier, having a conspicuous dip during the rainy season in West African countries.

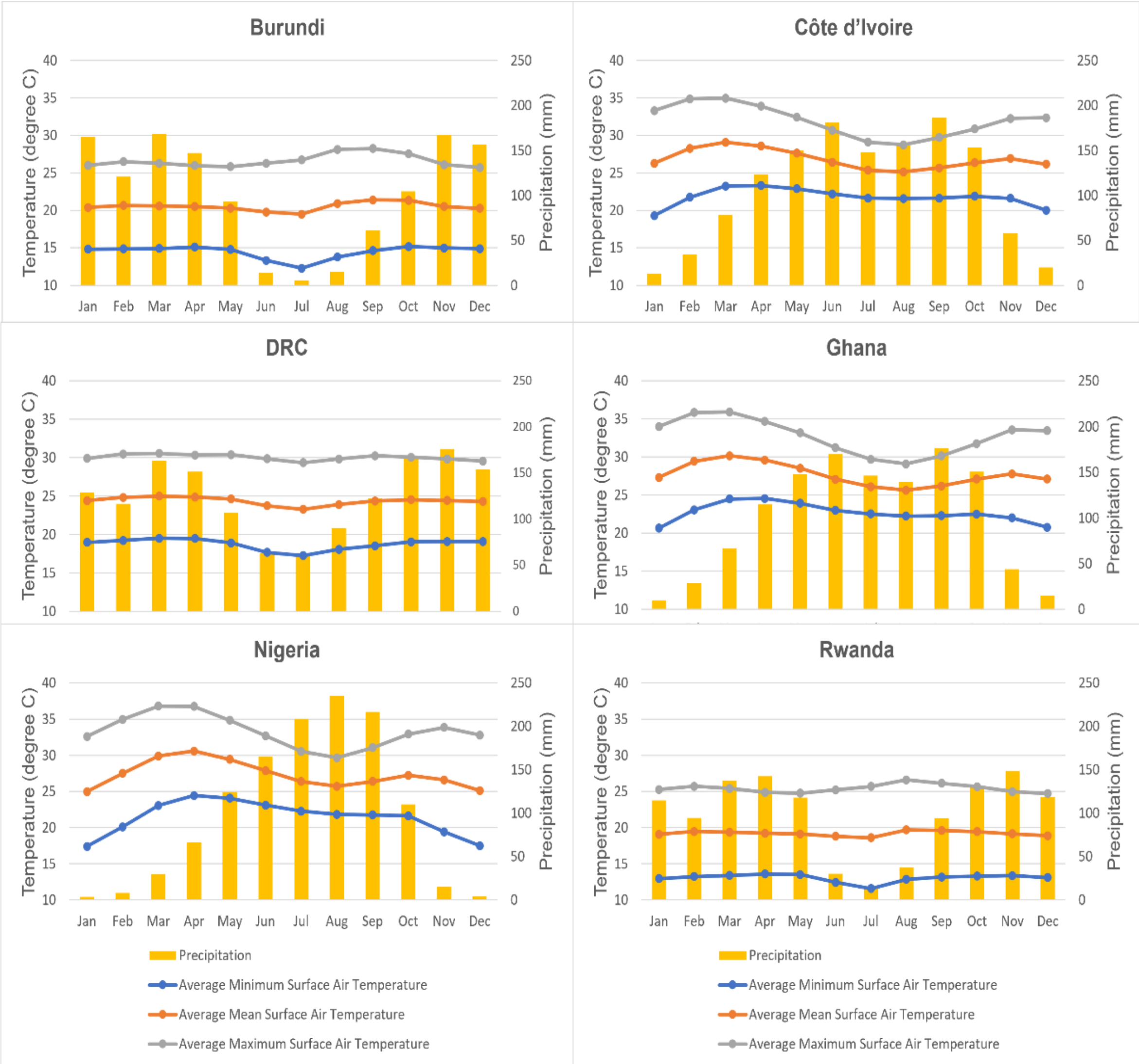


Figure 2. Monthly climatology of average minimum surface air temperature, average mean surface air temperature, average maximum surface air temperature & precipitation 1991-2022 in each country

Status of farming and food security

In the last decade, agriculture sector grew rapidly. Most of these growth, however, were observed in the case of cash/commercial crops (Table 2). These included cocoa, tea, cashew nuts, palm oil, and natural rubber. The area and production of staple crops such as maize, beans, corn, cassava, sweet potatoes, increased in the last decade, without any significant increase in yield/productivity. The yield of Banana, in contrast, increased with a simultaneous decrease in area. Overall, these countries are still a net importer of foodgrains. Food imports accounts for around 18% of the total import, the majority of which consists of cereals (16.5 - 35%). Higher dependency on global market for foodgrains and other key commodity, makes these countries highly susceptible to sudden increase in world commodity prices.

Majority of the crops grown in the region are rainfed and are grown by smallholder rural households who have limited access to quality seed, fertilizer, agrochemicals, or do not have enough credit to buy or rent agricultural machineries. These often result in low productivity (poor performance) of the crops grown in these countries. Other factors which are the result of poor purchasing power of famers include: (1) low adoption of improved seeds and technologies; (2) unmanaged pests, diseases and weeds in the fields; (3) less use of agrochemicals (fertilizers, pesticide, fungicide and others); (4) limited access to agriculture extension, and hence the insufficient knowledge of sound scientific agricultural practices; (5) inadequate information about weather, market, credit, insurance, etc. Unlike others, Côte d'Ivoire has high adoption of improved seeds, for crops such as Rice, Maize, and several other cash crops. However, the crops performance is severely affected by the increasing climatic variability as indicated in the previous section.

TABLE 2. LIST OF CROPS GROWN FOR DOMESTIC AND EXPORT PURPOSES

Country	**Top five commodities for domestic use**	**For export**
Rwanda	Beans, corn, cassava, sweet potatoes, and bananas	Coffee, tea, cut flower, palm oil
Côte d'Ivoire	Cassava, Fonio, Groundnuts, Maize, Millet, Rice, Sweet potatoes, Taro, Tomatoes, Yams	Cocoa, cashew nuts, Rubber, bananas, coffee, mangoes, sesame seed, sheanuts, palm nuts, cotton
Burundi	Cassava, bananas, sweet potatoes, plantains, beans (dry), vegetable (fresh) and maize	Coffee, cotton, tea, and palm oil
Nigeria	Maize, cassava, yams, rice and sorghum	Cocoa, sesame seeds, cashew nuts , cotton lint, palm oil and ginger
DRC	Maize, cassava, plantain, groundnut,rice	Coffee, cocoa, sugar and palm oil
Ghana	Maize, Yams, cassava, bananas and plantains	Cocoa, cashew nuts, palm oil, natural rubber, bananas, pineapples, and the vegetable sector

Methodology

This study employed a multi-step methodology to assess the landscape of climate and agronomic digital advisory services in six countries: Rwanda, Ghana, Nigeria, Democratic Republic of the Congo (DRC), Burundi, and Côte d'Ivoire. The methodology consisted of the following steps:

Step 1. Literature Review and Synthesis:

The first step involved conducting a comprehensive literature review to identify existing digital solutions in agriculture, with a particular focus on climate and environmental risk management. This review aimed to collect and synthesize results from previous studies, reports, and relevant publications on digital innovations that support agricultural resilience in the face of climate change. Key themes reviewed included the types of technologies being used, the platforms and analytical techniques deployed, and the overall impact of digital services on decision-making in the agricultural sector. The literature review also explored cross-cutting issues such as data privacy, harmonization, and institutional capacity.

Table 3. Description of digital agricultural solutions considered for review in West and Central Africa (WCA)

Digital Agricultural Solutions (DAGs)	Service category	Service
Agronomic	Advisory	Farm operation
		Storage
		Input application
	Extension	Extension
	Identification of P&D	On-farm identification
		Off-farm identification
		Remote
Agricultural service providers	On-farm operation	Ploughing
		Harvesting
	Off-farm operation	Transport
		Storage
Crop insurance	Risks	Drought
		Flood
		Pest
		Fire
Market information	Inputs	Seed
		Fertilizer
		Pesticide
	Outputs	Price
		Quantity
		Contacts off-takers
Finance	Input-credit	Seed
		Fertilizer

		Pesticide
	Investment	Investment
	On-farm operation	On-farm operation
	Output-credit	Output-credit
	Financial education	Financial education
Other DAGs	Others	Others

Step 2. Country-Specific Reports:

Based on the literature review, a report was produced for each of the six countries, addressing the current state of climate and agronomic digital advisory services in their respective agri-food systems (Table 3). Each report focused on the following key topics:

State of the Art of Existing Services: This section detailed the type of information provided by the digital services (e.g., weather forecasts, soil analysis, crop management advice), the frequency and format of the data (SMS, USSD, web-based platforms), and the analytical techniques used. Additionally, it examined the financial models sustaining these services, identifying whether they were donor-funded, government-supported, or market-driven. The reports also analysed the current and potential end-users of these services, including farmers, extension agents, service providers, and policymakers, and assessed the demand for such services—both current and potential.

Impact on Decision-Making: The reports further explored how these services contribute to better decisions in terms of climate adaptation and resilience. The reports looked at the capacity of institutions to administer, analyze, and use the data from these services for decision-making in agri-food systems.

Challenges and Barriers: A critical section of each country report was dedicated to identifying the main challenges associated with the implementation and scalability of and climate and agronomic digital advisory services. Challenges included financial constraints, local capacity gaps, language barriers, low digital literacy, lack of data harmonization, and data privacy concerns.

Potential of Digital Services and Value Chains: The reports also highlighted the digital services and value chains with the greatest potential for growth and scalability. This analysis was based on factors such as market demand, institutional readiness, and the ability to integrate digital solutions into existing agricultural practices.

Step 3. Report Synthesis and Recommendations:

Finally, the individual country reports were synthesized to provide a broader understanding of the regional landscape. The synthesis identified common trends, key barriers, and cross-country opportunities for collaboration and scaling digital services. Based on these findings, a set of recommendations was developed for stakeholders, including government institutions, the private sector, and development partners, to enhance the adoption and effectiveness of climate and agronomic digital advisory services.

RESULTS

Projected climate change and its impact on agricultural sector

Due to global warming, countries are expected to witness increased climatic variability in the near future. Frequency of hot days and average temperatures are anticipated to increase, along with more erratic and intense rainfall events. Some places are also expected to witness temporal shift in receipt of rainfall. Fig. 3 presents the change in the magnitude of ETCCDI for temperature and precipitation during different months of the year in the six countries of WCA. Given projected climate trends, the risk and intensity of flooding is expected to increase in Rwanda, Ghana, and Nigeria during the rainy season. In Nigeria, monthly precipitation is projected to increase throughout the year, with the maximum increase during August to October (between 32-38%; Fig. 3). In Ghana, precipitation is projected to increase during September to January, and decrease in remaining months. Similar trend is expected in Cote d'Ivoire; however, the magnitude of decrease (during February to May) is high, suggesting the possibility of experiencing water shortage during these months. In Rwanda, both increasing and decreasing trend is expected in different months: with the magnitude of increase ranging between 20-32% during December to February. Overall, climate change is expected to have predominantly negative impact.

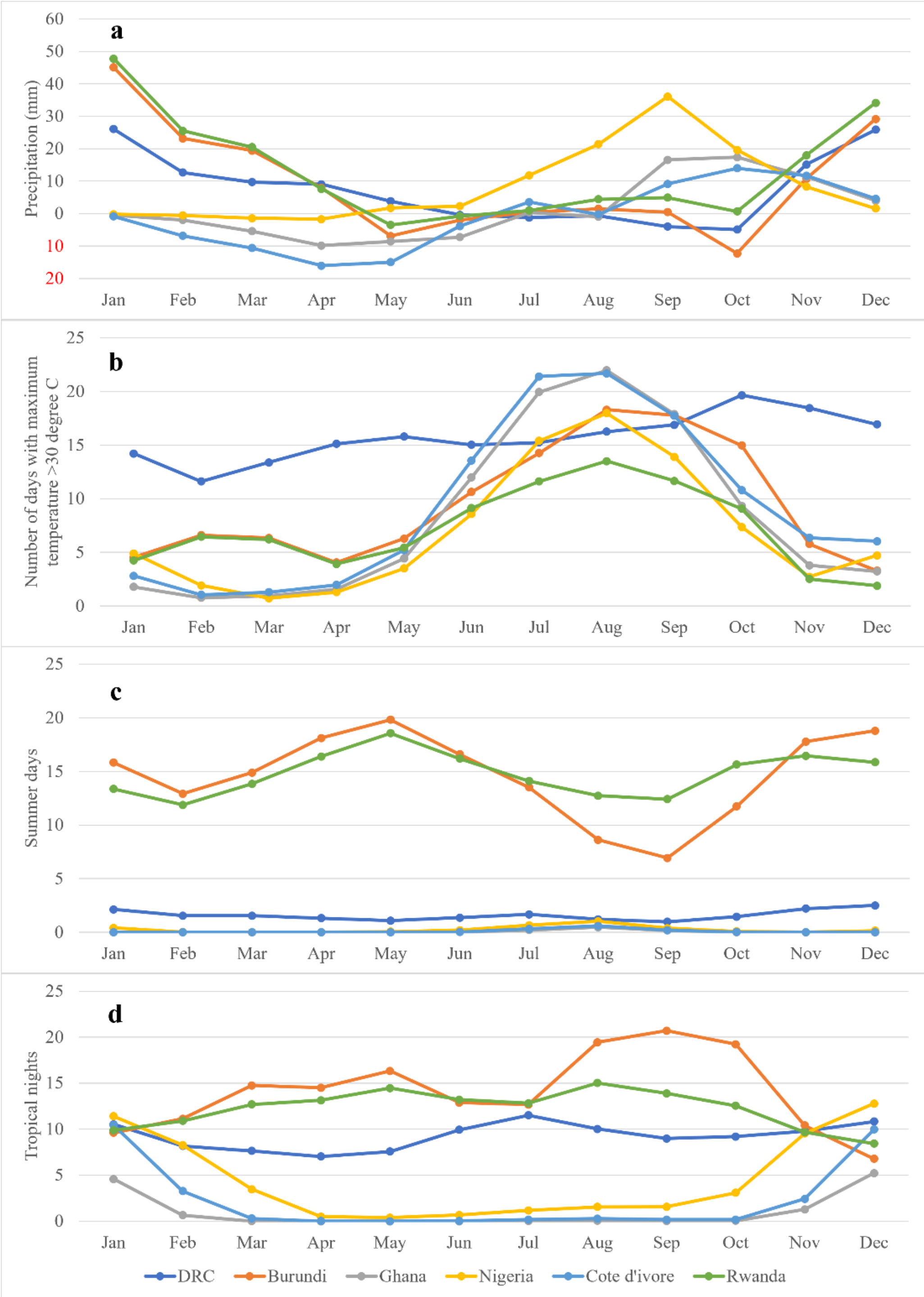


Figure 3. Trend of extreme climate change indices expected by the end of the century in different countries in terms of: (a) precipitation; (b) number of days when maximum temperature is greater than 30°celsius; (c) summer days: number of days when daytime temperature is greater than 25^{0}celsius; and (d) tropical nights: number of days when minimum temperature is greater than 20°celsius.

Agriculture sector is expected to be particularly affected by changing weather patterns, since crops are produced by the smallholder poor farmers mainly as a rainfed crop (Nahayo et al. 2019; FAO, 2022). Because of the expected changes in temperature and rainfall patterns, some crop-growing areas are expected to become less suitable or even unsuitable for production, forcing farmers to shift to other crops or production areas, creating uncertainty and potentially risking their livelihoods. Prolonged periods of heatwaves and dry spells will likely lead to lowered water levels, and therefore decreased crop and livestock productivity, as well as increased livestock mortality. The response of several staple crops (bean, maize and rice) to changing weather pattern is variable. Maize yield is expected to decrease in Burundi, DRC, Ghana, and Cote d'Ivoire, and increase in Rwanda, and Nigeria. Rice yield is expected to increase in DRC, but decrease in Cote d'Ivoire, Rwanda and Nigeria. Places receiving more rainfall may suffer from changed pests and diseases dynamics. The production of Cassava, which is more adapted to hot and dry conditions, may be affected due to waterlogging and extreme rainfall (for example, in Nigeria; The World Bank Group, 2021), or due to reduced water availability (in Rwanda; Nyasimi et al. 2016). Livestock production is also threatened by heat waves and desertification.

Vulnerability and readiness to climate change

In response to the ongoing and expected climate change, most of these countries were identified as highly vulnerable to climate change and least ready to combat its ill-effects (ND-GAIN Index[1], Figure 4). These were also ranked high in terms of the vulnerability of their food sector ((University of Notre Dame, 2021). DRC followed by Burundi are the most vulnerable countries where there is a need of immediate investment and innovations to improve readiness and a great urgency for action. Among the six African countries under study, Ghana is recognized as least vulnerable to climate change impacts.

[1] The Notre Dame Global Adaptation Initiative (ND-GAIN) Index ranks 181 countries according to their vulnerability to climate and other challenges, and their readiness to improve their resilience. The index consists of several components, including the food score, which reflects a country's vulnerability to climate change in terms of food production and demand, nutrition and rural population.

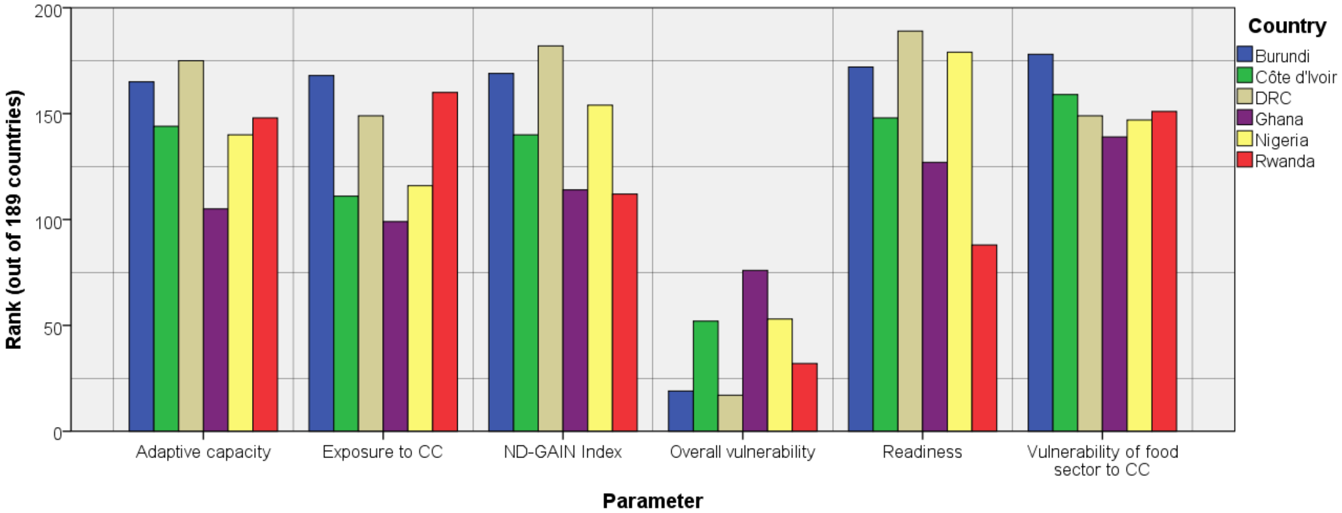


Figure 4. Ranking of countries by ND-GAIN index, Vulnerability, and Readiness to climate change (2023)

EXISTING CLIMATE AND AGRONOMIC DIGITAL ADVISORY SERVICES AND OTHER DIGITAL AGRICULTURE SERVICES

Each of the six countries has developed diverse solutions to provide climate and agronomic advice to farmers. Many of these services rely on mobile-based platforms, such as SMS and USSD, to disseminate weather forecasts, agronomic advice, and information on market. Fig. 5 shows the major digital agricultural solutions (DAGs) available in the six countries. Agronomic, climate services, and market information together hold a major share of DAGs in all countries under study. In agronomic services, advisory and extension services seem to be a priority in all countries (Supplementary Fig. 1). P&D identification services were reported in greater number from Ghana, Nigeria, and Rwanda, and only a few from other countries.

Digital agriculture solutions focussed on climate were provided mainly in two forms, either as Climate information services (CIS) or in the form of Climate Smart Agriculture (CSA) practices. Under CIS, information related to rainfall, wind, pest, and seasonal were provided. Information related to CSA were provided under six sub-categories: cropping system, fertilizer, seed, ploughing system, water management, and all CSA. Result indicated that majority of the innovations (involved in climate services) in these countries were providing information related to CSA (~ 57%) and remaining ~ 43% as CIS (Supplementary Fig. 2). Country-wise distribution however shows that this figure varied significantly between countries. Nigeria, Ghana, and Rwanda have substantial focus on CSA, whereas Burundi, CIV, and DRC have a greater focus on CIS.

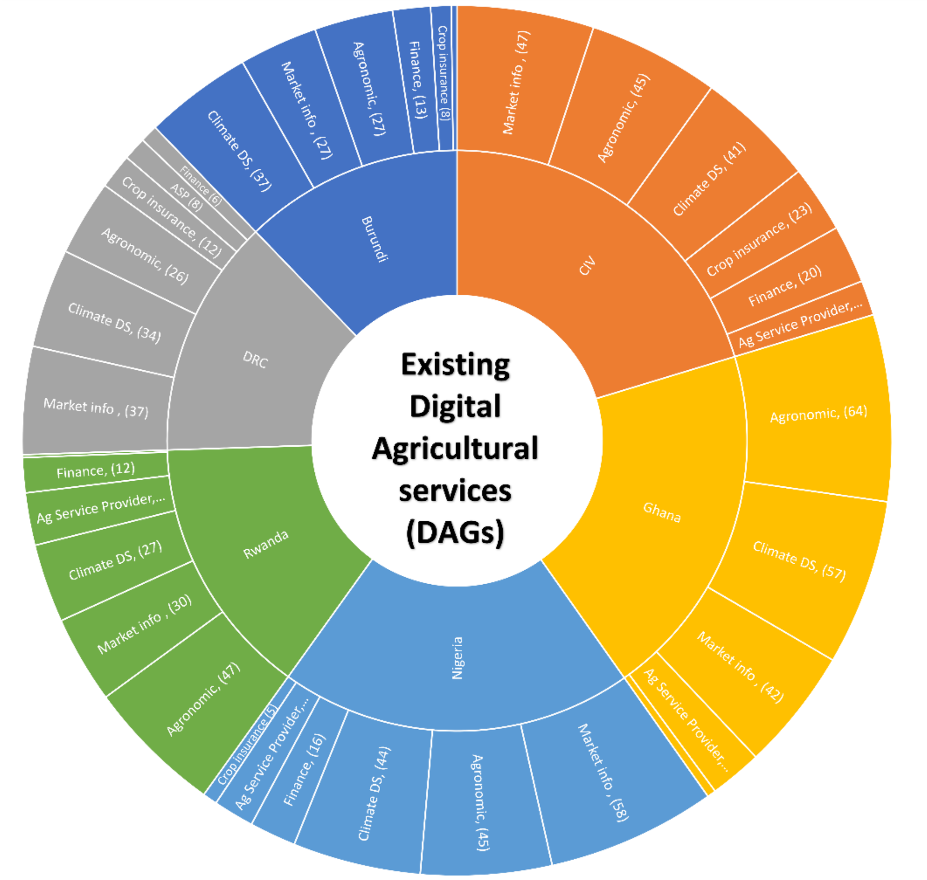


Figure 5. Sunburst chart showing existing digital agricultural services in six countries of WCA

Analysing the type of services offered under the two broad categories of digital climate solution, it is clear that 'all CSA' (under CSA) and 'rainfall' (under weather forecast) constituted 33.1% and 31.7% respectively (Table 4). This suggests that innovations were more focussed at providing information about rainfall along with different CSA practices together to meet the diverse needs of farmers. It is however important to note that innovations providing 'all CSA' services were reported only from Ghana, Nigeria, and Rwanda, and none in other countries. In Burundi, Cote d'ivoire and DRC, innovations were involved in providing individual components of CSA, and not altogether.

Under CSA services, Rwanda (58.8%), Nigeria (47.2%) and Ghana (42.8%) have a greater proportion of innovations providing services under "All CSA" category (Table 4). Water management percentages were fairly consistent across the countries, but Burundi (25%) stands out for having a higher proportion of its activity in this category. Cropping system and Seed percentages tend to be higher in CIV, but much lower in Rwanda. Rwanda lacks innovations providing individual services related to seed, cropping system, and ploughing system. In DRC, seed and fertilizer hold a greater share of innovations (Table 4).

Table 4. Proportion of innovations (%) providing different digital climate services in WCA

Country	CSA						CIS			
	All CSA	Cropping system	Fertilizer	Ploughing system	Seed	Water mgt	Rainfall	Seasonal	Wind	Pest
Burundi	0.0	18.8	18.8	18.8	18.8	25.0	38.1	4.8	33.3	23.8
CIV	0.0	30.8	15.4	15.4	23.1	15.4	42.9	0.0	28.6	28.6
DRC	0.0	16.7	33.3	8.3	25.0	16.7	36.4	0.0	40.9	22.7
Ghana	42.9	16.7	14.3	7.1	7.1	11.9	20.0	46.7	0.0	33.3
Nigeria	47.2	19.4	8.3	2.8	11.1	11.1	0.0	87.5	0.0	12.5
Rwanda	58.8	0.0	23.5	0.0	0.0	17.7	20.0	60.0	0.0	20.0
% of grand total	**33.1**	**16.9**	**16.2**	**7.4**	**11.8**	**14.7**	**31.7**	**20.2**	**23.1**	**25.0**

In terms of CIS, innovations in Ghana, Nigeria, and Rwanda have relatively greater focus on providing seasonal weather forecast, compared to wind, pest, and rainfall individually (Table 4). It was also observed that pest forecast was provided in all six countries. Innovations in DRC provide more rainfall and wind forecast, with minimal attention to seasonal forecast. In terms of frequency of these services, about 93% of them were provided/available throughout the crop growing period, whereas only 5% were provided at seasonal scale and remaining 1.25% once in a year.

Results also indicate that innovations involved in providing market information were reported in greater numbers in Nigeria, Cote d'Ivoire, and Ghana (Supplementary Fig. 3). These three countries together constituted around 60% of such innovations reported. Compared to the market information, a significant drop/reduction was observed in terms of number of innovations providing finance/credit in all countries (supplementary fig. 4). This is especially worrisome for countries such as Ghana and DRC, where there is a lot of potential for agricultural growth. Likewise, agriculture service providers for on-farm and off-farm operations were also reported to be fewer (supplementary fig. 5) in these countries. Crop insurance to risks (such as Drought, flood, pests) is another DAG, which was reported from Burundi, CIV, DRC, and Nigeria, however, the same was limited/not available in Ghana and Rwanda (Supplementary Fig. 6).

Overall, country-wise distribution of these digital solutions suggests that CIV, Ghana, and Nigeria have more and comparable number of innovations (~20% each), whereas Burundi, DRC, and Rwanda have relatively fewer innovations. Smaller number of innovations in Rwanda and Burundi might be due to its small size and uneven topography. This number in DRC however indicates a gap and areas for future development. There is an urgent need to put emphasis on the development of services lacking in respective countries. The review also revealed that most of these innovations were launched during the last decade (Fig. 6) with a greater involvement of the private companies (Fig. 7). Majority of digital innovations (>82%) were marketed by the private sector, whereas the public DAGs contribution was very low (4%; Fig. 7).

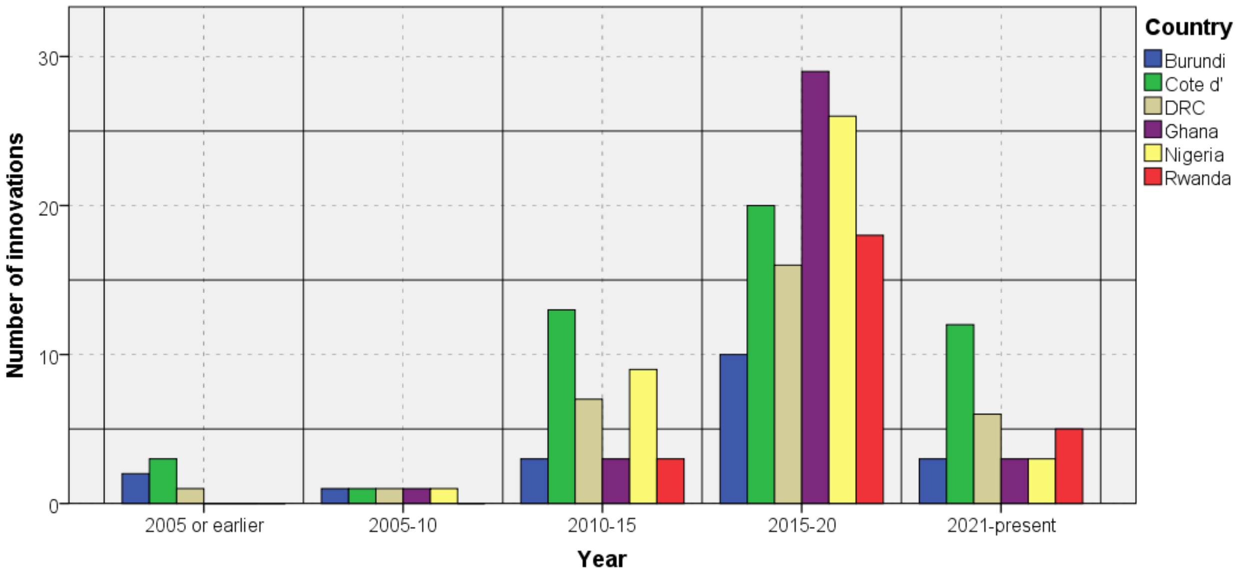


Figure 6. Time period of launch of digital agriculture breakthroughs in each country (as of 2022)

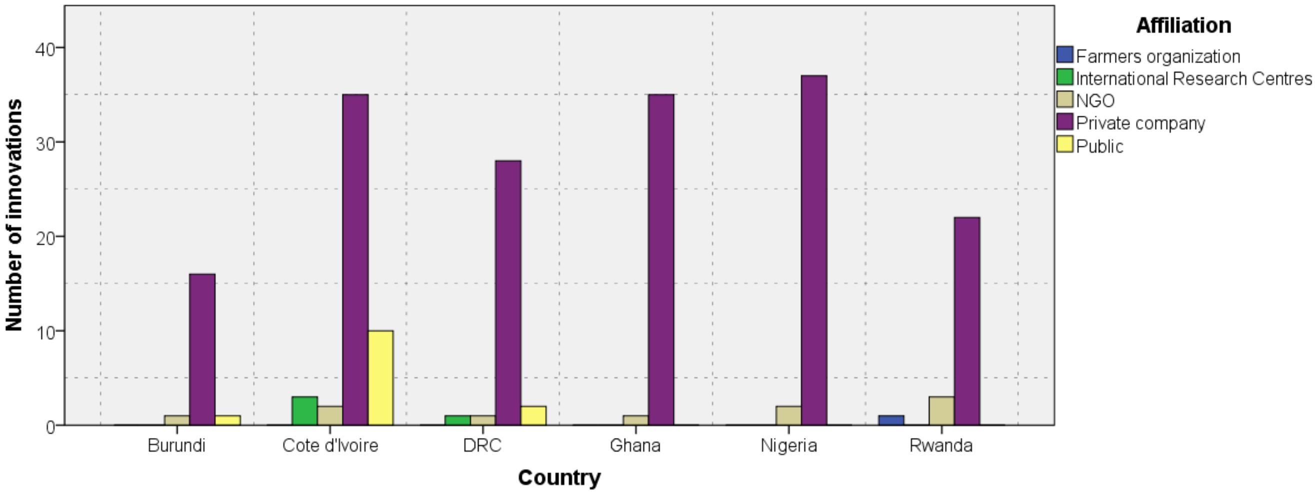


Figure 7. Organizational affiliation within the digital agriculture ecosystem in different countries.

USERS OF CLIMATE INFORMATION AND AGRO-ADVISORY SERVICES

This study identified three different user groups of digital agro-climatic technologies and advisory services. They were: (1) producers/farmers (2) service providers and (3) policy makers. For each user group, their needs, the type of services they use, their motivation for accessing their services and the main barriers they face in accessing these services were different. In this paper, we have discussed only about producers as a user of these information.

Producers/farmers were the main beneficiaries of agricultural digital technologies. This user group had diverse needs and interests: (1) receiving more frequent and better tailored agro-advisory services; (2) receive climate information in near-real time and apply it to increase crop productivity; (3) improved access to insurance and financial services, to market opportunities and price information, and to inputs and other production support services; (4) access to post-harvest storage facilities; (5) access to inputs and mechanization etc. In order to meet out the diverse needs of farmers, companies came with the offer of bundled services. Findings of the review indicate that there was relatively high level of awareness of the existing digital technologies, as well as their adoption (except Ghana and DRC) among this user group. The number of registered users receiving benefit of these services were highest in Rwanda, followed by Nigeria and Cote d'Ivoire (Fig. 8). However, the capacities to use the tools, interpret their information, and moreover, put it into practice were limited and varied between different types of actors. Main barriers faced by this user group were: (1) limited technology ownership; (2) low ability to pay for services; (3) low literacy rates; (4) gender gaps; (5) limited access to support services; and (6) cultural and language barriers.

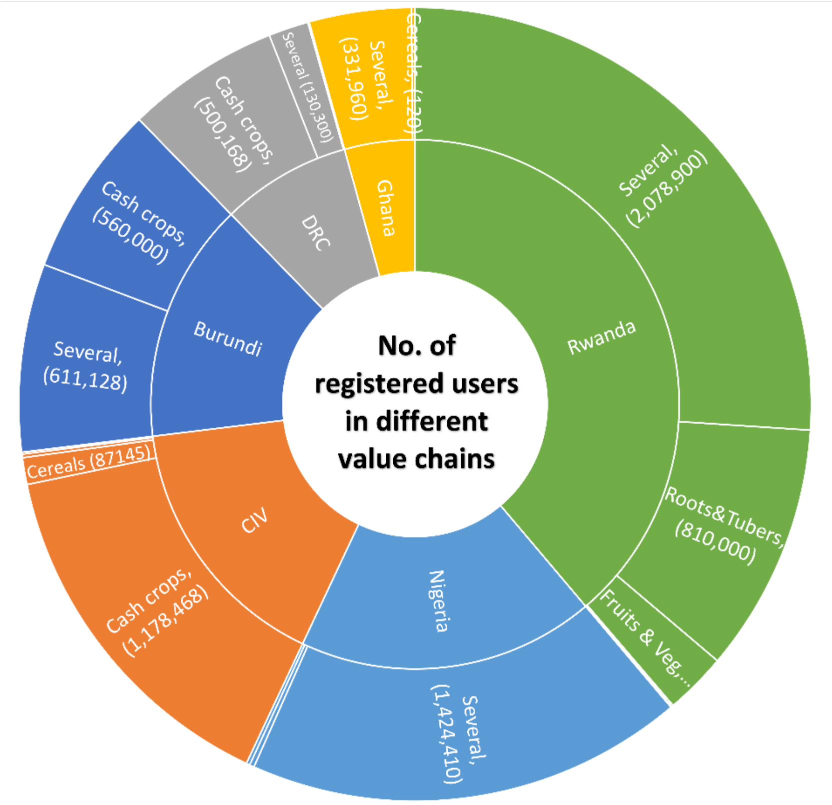


Fig. 8. Existing users of digital agricultural solutions in various value chains

EXISTING TOOLS FOR IMPROVING LOGISTICS IN VALUE CHAINS AND ACCESS TO FINANCIAL AND INSURANCE SERVICES.

Extension and Research services: Public extension services in Ghana, Rwanda and Nigeria is structured on a decentralised system. The extension system is based on *Training and Visiting scheme* in Nigeria and is called *Twigire Muhinzi* in Rwanda. Nigeria being home to the IITA and number of NGOs, has the largest agricultural research system in Sub-saharan Africa. The decentralised farmer-to-farmer model of Rwanda consists of two approaches: Farmer Field Schools and Farmer Field Promoters. The first is based on a learning-by-doing model in which farmers observe field practices and are trained by farmer facilitators. The second is based on the selection of a farmer promoter in each village, who is trained with extension tools and then disseminates the knowledge within his or her community (Clarkson et al., 2017). The extension system has been effective in terms of coverage and inclusiveness.

Policy landscape: Ghana (after Kenya) has been at the forefront of establishing a regulatory framework to enable the development of the ICT sector for digital transformation in Africa (Lozanova et al., 2022). Liberalization of economy allowed for a rapid penetration of foreign investment in the development of digital infrastructure, particularly in the provision of telecommunication services. In the past decade, the government of these countries launched several programs and policies, each aimed at facilitating the penetration of ICT, and leveraging the digital technologies and open data for agriculture sector. The use of digital technology for agriculture included: (1) creation of farmers' digital identity; (2) electronic payment system; (3) technology transfer and input delivery; (4) dissemination of weather and market data; (5) diversification of economy; (6) promotion of import substitution strategies in selected value chains, etc. However, problems related to the selection of the beneficiary population, the supply of inputs and deficiencies in the generation of data for monitoring and evaluation have been reported (Pauw, 2022).

Business environment: Availability of immense development opportunities as well as the liberal policies adopted in these countries have favoured foreign investment over the past two decades and the development of public-private partnerships. In the past decade, several projects were launched to improve business operations, facilitate digital payments, and improve business access to various financial support mechanisms. They have contributed to the establishment of several tech hubs, digital centres, incubators and accelerator programs across the country, the network of which is further supported by CGIAR initiatives (FAO & ITU, 2022). The Government, private organizations, and NGOs are also actively involved in creating a wide range of innovation centers and business incubators to support new initiatives and develop entrepreneurial capabilities, including some aimed at start-ups dedicated to agriculture and climate-related issues.

CHALLENGES OF EXISTING TOOLS IN COMPLEMENTING DIGITAL AGRICULTURE

Size of the country, limited infrastructure, illiteracy, lack of accessibility in certain areas due to social unrest are some of the reasons for the low penetration of digital technology in different regions. The farming community, in absence of a good/sound infrastructure (electricity, cellular network, road, market etc.) often suffer. In this section, we have provided a brief overview of these challenges one by one.

Infrastructure landscape (electricity, access to all-season road, network connectivity): Infrastructure development in rural areas remains as one of the key limitations for agricultural development in most of these countries. Electricity is one of the essential infrastructures to complement the digital solutions supply in any area. In terms of access to electricity, Ghana (86 %) is one of the leading countries in Africa followed by Côte d'Ivoire (62.6 %), Nigeria (55.4%) and others, with Rwanda (37.8 %) having the least coverage (Fig. 9). The number however, varied between the urban and the rural population, with lesser coverage among the rural population. According to (FAO & ITU, 2022), only 3.09% of the population have access to electricity in rural areas of Burundi. Therefore, post-harvesting facilities which need electricity is also lacking.

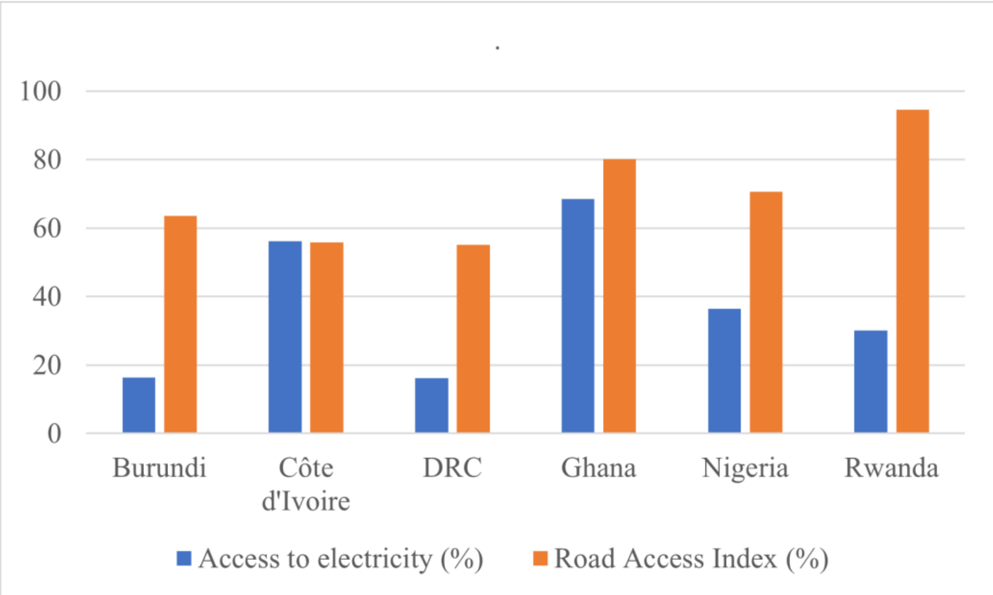


Figure 9. Status of total population, electricity and access to all-season road in different countries (source: CIESIN - Columbia University. 2023)

Digital landscape: Having access to electricity enables a population to stay connected through the internet and share real-time information. However, ability of an individual to pay for the internet is another major driver in these countries. The subscription cost for having a fixed broadband accounts for 45.7% of the household expenditure, whereas the mobile data consumption can range from 7.8%

to 11.1% in Rwanda (ITU, 2021). Similarly, the cost of internet was very high in other countries as well. This high cost of internet can impact the adoption of Climatic and agronomic digital advisory uptake. The mobile-cellular network serves all parts of the population, however, only 69% uses internet. A significant gender imbalance was observed in the usage of internet. Internet is available to a greater fraction of the male population than to the female population.

***Literacy gap**:* Although literacy rate among the adults (15 years and above) was more than 75% (except Nigeria; UNESCO Institute of Statistics) in most of the countries, digital skills were ranked as the top barrier to mobile internet adoption by both male and female mobile users (Steinke et al., 2024). Compared to other countries in the west- and central Africa, literacy levels are high in Ghana and Rwanda. Furthermore, although computer exists as a technology that guarantees fairly complete access to the internet, yet it remains technically and economically out of reach, especially among those who are poor and illiterate (Loukou, 2012). In rural areas, reading and writing are the biggest concern for both male and female individuals, who are engaged in farming activity for the sustenance and livelihood. The most affected by digital illiteracy tends to be poor, women, living in rural areas and over 35 years old. An alternative, therefore, could be presentation of the facts and information in local/regional language in written, voice or video form to facilitate rapid understanding by the users.

Gender and Social Inclusion: Although great strides have been made in terms of women's access to primary and secondary education, and there is significant participation of women in the labor market, yet significant gap is observed at both national and rural levels. Gender gaps in terms of literacy, educational attainment, access to vocational training, income level, political empowerment etc. are among the highest in the world (World Economic Forum, 2022). Cultural and religious barriers, limited access to education, finance, technologies and capital, less access to ICT tools, among other factors, have created these gaps (AFEX, 2021) and have hindered women's use of digital services (Partey et al., 2020).

TABLE 5. STATUS OF WOMEN AND YOUTH IN AGRICULTURE SECTOR

		% of women	**% of rural youth**	**Ranking of each country in terms of GGGI* in terms of**

Name of countries	% of women owning a land	employed in agriculture	unemployed	economic participation and opportunity	education attainment	health and survival	political empowerment
Burundi	51	55.2	-	8	120	27	41
Cote d'Ivore	12	42.9	-	111	128	33	112
DRC	25	57	-	83	144	43	116
Ghana	38	38	20	80	105	36	111
Nigeria	35	30	28	54	127	99	142
Rwanda	-	61	30	67	110	55	9

*Ranking of each country in terms of Global Gender Gap Index (GGGI) out of 146 countries

Agriculture is the main source of employment for more than one-third of women, and about half of those living in rural areas (ILO, 2021). Although one-third of the women population owns a land (Table 5), they are disproportionately affected by lower incomes, higher rates of food insecurity and limited access to technologies and credit. These gaps also translate into less access to digital technologies. Women represent barely a quarter of the user base of digital technologies in sub-Saharan Africa (Abdulai et al., 2022), and this have made women less likely to benefit from the advisory and extension services (Jost et al., 2015; Terefe et al., 2022). Coulibaly et al. (2017) also concluded that lack of ownership of communication assets and non-participation in social groups could be the reason for women to be significantly less aware of climate information and have less access to climate information than men.

Extension and Research services: Although the service provision is decentralized across these countries, in Ghana it has experienced a burden to an underserved capacity of extension agents. Current capacity ratio is much above than the number recommended by the FAO (1:500:: public extension worker: farmers). This ratio in Nigeria was even worse than in Ghana i.e. only 1 extension worker is available for 7500 farmers in Nigeria, whereas in Ghana this ratio is 1:1500 (Loukos & Javed, 2018). Women are poorly represented in the extension services i.e., only 5 - 28% of the public extension agents are women. Therefore, it is still a major constraint to effectively introduce new technologies to women farmers in areas where sociocultural beliefs and practices prohibit interaction between men and women

(Nyarko & Kozári, 2021; Terefe et al., 2022). In order to increase the participation of women in agriculture, government have committed to ensure that at least 30% of the beneficiaries of extension services are women (Terefe et al., 2022).

Furthermore, the extension programs have come to rely heavily on non-government funding sources and has been affected by reduced allocation of public funds (Downie, 2017; Priebe, 2022). The involvement of private sector, farmers' organizations, NGOs, food industries and traders, input suppliers, faculties of agriculture in public universities, and AgTech companies have emerged as the provider/supplier of agricultural extension at the national level (Naswem & Ejembi, 2017; Awolala et al., 2022). Public servants, however, still account for the vast majority of extension workers (Oyinbo et al., 2020), and public extension services remain the most viable platform for agricultural extension, and thus have been an important catalyst for scaling up agricultural technologies. Despite of their importance, the public extension service has been reported to have poor digital capabilities: (1) low endowment of ICT tools, (2) lack of training and capacity development, (3) poor infrastructure and equipment, (4) low adoption of ICT tools, and (5) gender disparity among the extension officers (Nyarko and Kozári, 2021). In recent years, however, several initiatives have been launched to address these deficiencies and modernize the existing extension system by increasing participation of private sector, focusing specifically on cash crops.

Economic landscape*:* Although *business landscape* indicates availability of immense development opportunities for service providers in these countries, access to financial sources is a major challenge for the producers, especially among the small holders. The lack of investment in the agricultural sector, difficulty in accessing credit and problems with repayment of the same have also become an important barrier for the producers. Their inability to buy these services or limited access to the financial resources will have a direct consequence on the dissemination of climatic and agronomic digital advisory services. This is especially for the farmers in the rural areas, who may not be in a position to receive the information and respond timely. The emergence of crowdsourcing as a financing model, however, has emerged as an alternative for financing some of the agricultural operations.

Policy landscape: Public investment in agriculture is low compared to other sectors in most of these countries (except Rwanda; Downie, 2017). This represented almost none to about 2.5% of the government budget, being one of the lowest in Africa (FAO, 2022). In the last decade, this public spending has however, declined by about 8% in Nigeria, and contrarily increased in Ghana. No reports were available for Burundi, Cote d'Ivoire, and DRC. Despite their importance, it is estimated that the government bodies responsible for implementation of agricultural policies and provision of public sector services are operating with about half of their required staffing, for example, 47.6% in Ghana (Nel et al., 2019).

Lack of trust (including breach of contracts, unfair prices, corruption etc.) along the value chains is also an important factor that limits their development. Therefore, some initiatives have developed digital innovations to increase trust in agricultural value chains. This includes digital innovations such as: (1) implementation of certification and traceability systems for cash crops; (2) information collection and dissemination mechanisms; (3) using blockchain technology to secure land transactions, as well as financial transactions; and simultaneously (4) provide advisories.

Climate change: The expected impacts of climate change are predominantly negative. This is because these countries have low adaptive capacity where farming is predominantly rainfed and are undertaken by poor rural households. In the past decade, several climate-related disasters affected millions of its inhabitants (CRED & UCLouvain, 2022) and resulted in direct economic losses worth billions of dollars annually (USAID, 2017). Most of these disasters were either due to heavy rainfall or deficit rainfall. These losses were the result of crop damage, loss of pasture and water sources, loss of animals, hunger, disease outbreaks, asset depletions, malnutrition and migration etc. which are likely to keep increasing (The World Bank Group, 2021).

Table 6. Main challenges identified in complementing digital agriculture solutions.

Country	**Costs of services**	**Data harmonisation**	**Data privacy**	**Digital literacy**	**Languages**	**Local capacity**
Burundi	NA	NA	NA	NA	NA	NA

CIV	NA	NA	NA	NA	NA	NA
DRC	NA	NA	NA	NA	NA	NA
Ghana	35	24	27	28	36	35
Nigeria	31	26	32	36	39	29
Rwanda	23	15	19	18	19	25

*NA: Not available

In addition to the above-mentioned challenges, Table 6 presents other challenges identified while implementing digital agriculture solutions. Information about these challenges were not available from Burundi, CIV, and DRC. In Ghana, cost of services, language and local capacity were found to be the main challenges while implementing digital solutions.

Data Harmonization and Data Management

Unlike many similar exercises, this mapping study includes a focus on data harmonization and data management, highlighting their importance for effective digital advisory services. The findings indicate that:

In DRC, data from agricultural services is stored independently by various service providers, and there is little to no coordination between them in terms of data harmonization. The absence of a common platform for data storage and integration complicates efforts to create a standardized system for managing agricultural data. Metadata is often missing, further impeding data sharing and interpretation.

Burundi faces similar challenges to DRC, with most digital services storing data independently, without harmonization. Different organizations collect and store data using their own systems, and there is no centralized data repository or framework for integrating data from multiple sources. As in other countries, the lack of data harmonization makes it difficult to optimize the use of digital services for decision-making in agriculture.

Cote d'Ivoire struggles with the absence of a unified data harmonization framework. Agricultural service providers manage data independently, without adhering to common standards, leading to difficulties in sharing and consolidating information across platforms. The country lacks specific laws regarding agricultural data standards, and although data privacy laws exist, they are under-enforced. Each service provider stores data based on individual preferences, making harmonization a significant challenge.

In Ghana, data harmonization efforts are overseen by the National Information Technology Agency (NITA), and policies like the National Data Sharing Policy aim to facilitate more effective data management. Ghana's Data Protection Act and National Cybersecurity Policy and Strategy provide a foundation for secure data handling and sharing. The Ghana Open Data Initiative has started integrating agricultural data, but harmonization across various platforms, such as MoFA's National e-Agriculture Program, is still in early stages. Numerous independent platforms (e.g., Farmerline, Esoko) gather data, but full integration remains limited

Nigeria’s data landscape is governed by the National ICT Policy and the Nigeria Open Data Policy. While Nigeria has a large number of agri-tech companies offering digital agricultural services, data harmonization is a significant challenge. Each platform operates largely independently, and there is no standardized approach to data collection or sharing. Mobile networks are crucial for digital services, but gaps in the regulatory framework regarding data privacy and harmonization limit the potential of digital agricultural data sharing Rwanda has made some progress in data harmonization efforts, particularly through the Rwanda Open Data Portal. However, the platform is still in its early stages, with limited operability and data availability. Key climate and agricultural services in Rwanda remain fragmented, with different organizations managing their data independently. Although efforts to integrate data are in progress, much work is needed to ensure a unified approach that allows seamless data sharing across platforms.

EXISTING DISSEMINATION TOOLS

The spread of digital agricultural services has been made largely through bundled services. Review suggests that these services were made available by combining CIS-CSA based agro-advisory with other services, such as (1) telephony services (such as ESOKO, VIAMO and FarmerLine); (2) logistics, value chain traceability and payment services (Caargil and Farmerline); (3) financial and insurance services (AgUnity and AgroCenta); (4) electronic services for financial transactions; and (5) the logistics solutions for access to post-harvest infrastructure. Bundled services have been a model that has been able to meet various needs of a target user by complementing their offer with complementary services.

DISCUSSION

Crop performance in sub-Saharan Africa is undermined very often by the erratic and non-uniform rainfall conditions, since farming is predominantly rainfed in the region (<2% potentially irrigated area; Nahayo et al., 2019; FAO, 2022b). The change in precipitation patterns and resulting localised heavy rainfall events on a few days of the year and drought conditions otherwise, has become a major challenge for the farming community worldwide (Donat et al. 2016) including these countries (Monerie et al. 2021). Given projected climate trends, the risk and intensity of intense rainfall events (and prolonged dry spells) is expected to increase during the wet (dry) season, making them extremely vulnerable to the effects of torrential rains and floods (drought-like situation). The effect of these weather extremes, however, can be mitigated by using localised short-to-medium weather forecast as well as seasonal forecast (Rathore et al. 2011; Bal and Sarath Chandran, 2021; Dissanayeke et al. 2021). Climate-smart practices have proved to be useful in supporting farmers in making informed decision and simultaneously minimising the input costs.

Given the importance of the agriculture sector to the economy and food security in Sub-Saharan Africa, and considering the imminent risk posed by climate change to the region's food systems, it is imperative to work on strengthening national and regional-level initiatives to increase the productivity of food systems while making them more sustainable and resilient. Digital agriculture has positioned itself as one of the main sources of action, more so considering the favourable outlook of the countries in terms of (1) digital infrastructure, (2) the short- and medium-term strategic plans of the government, (3) increased bank participation in agricultural investments, and (4) the collaborative framework between government, NGOs, and private sector for the development of the sector. However, the study has identified several challenges in successful implementation of the digital technology and its usage for agriculture sector.

Mapping of agronomic and digital services in the six countries of WCA suggest that several digital innovations were developed during the past decade. They have been identified as promising in offering many services. Most of these innovations, however, were tailored to meet specific needs (for example, credit, insurance, seed, nutrition recommendation, pest and disease management, market price, etc.), and a specific group of farmers (for example, banana, coffee, tea, rice, and others). So, a farmer interested in getting more than one service will have to pay individually for each of these services.

Considering the economical and farming condition of these small holder farmers in WCA (resource poor, and grow crops under rainfed conditions), it was suggested to design a package of services that can provide all essential services to the farmers at a nominal fee. This is based on the concept of bundled climate services, a service given by combining CIS-CSA based agro-advisory with the other services. Providing these services as a well-defined package is considered to be a practical, and less demanding (more economical) solution for both farmers as well as the services providers (Ouedraogo et al., 2022; Terefe et al., 2022). This, however, needs the development of essential infrastructures (electricity, road, mobile connectivity), gender and social inclusion, involving more youth (including women) in extension, supporting new start-ups/entrepreneurship, improving basic education level as well as digital literacy, etc. In order to meet these requirements, the government bodies in these six countries have partnered with private sector to support the development of necessary infrastructure and services required for complementing digital technology led agro advisories. They have been working to raise awareness/literacy about digital technology and their use to provide multitude of services, including (1) providing access to all kind of near-real-time farm information (seed, credit, instruments, insurance, market price, etc.) available on web/app, (2) money transfer/transaction, (3) insurance, (4) record keeping, (5) policy, (6) monitoring and tracking of products, (7) agro-advisory etc.

Despite of the significant progress made by the countries in this regard, there exists an imbalance between the urban and the rural population, with lesser coverage among the rural population. Furthermore, the low literacy level and inability to pay for internet keeps the small holder farmers technically and economically away from being able to access CIS-CSA advisory services. Considering the existing services and challenges in development and provision of

CIS-CSA related advisory, ensuring gender equality and social inclusion in the Agricultural e-Extension Services Strategy is essential. It is of utmost importance to work on digital literacy, focusing on addressing the existing gaps in terms of gender and age groups, as well as designing mechanisms that can be adapted to the needs of users. The development of human capital is equally important. Initiatives such as (1) increasing participation of youth (including women) as a stakeholder, (2) building capacity, (3) supporting youth entrepreneurship (for example, develop local industry), (4) increasing awareness about available services and technologies by participating in social groups, (5) digital literacy, (6) providing training to serve as extension agents, (7) providing land rights, etc. can be helpful in reducing migration out of rural areas.

The governments of Rwanda and Nigeria have implemented several programs and policies (National Agricultural Technology and Innovation Policy, 2022; National Youth Policy, Digital Agriculture Strategy) to achieve different objectives. These were aimed to improve access to credit, land, skills development services, education, and employment in agriculture-related sectors. Some of the activities include: (1) simplification of regulations to make it easier to start and operate businesses; (2) tax exemptions for small businesses; (3) reduced airfares for rural businesses; and (4) greater inclusion of youth in public agricultural extension and research systems (Clarkson et al., 2017). A report of baseline survey indicates that young, educated farmers were more promising as potential early adopters of digital tools, based on their high scores on sub-components such as social opportunity and reflective motivation (McCampbell et al., 2018).

Besides the digital technology and stakeholders' involvement in developing agro-advisory process, availability and accessibility of open data (crop, market, weather) have been identified as equally important. Open data along with digitalization have great potential to transform and modernize today's agriculture. However, because of little cross-organisational collaboration, these data are accessible only to the public organisations and least with the private sector. This is another major constraint which is limiting the capability of new start-ups and entrepreneurs in venturing out and providing any kind of service. Furthermore, digital technology often comes with cybercrime and data protection and privacy issues. Policies have been implemented to manage data-related issues, including data protection and data sharing principles. The mapping found a few legislations in Nigeria, Ghana, and Rwanda and none in Burundi, Cote d'Ivoire, and DRC, to address any data-related issues in agriculture.

CONCLUSION

To understand the positive impact of climate advisory services on productivity and improved livelihoods, there is a need to strengthen the public capacities and cooperation with the private sector. It can also help in expanding the reach of these services (data collection, extension system, financing, and others). The countries have established a strong policy framework and government support to attract investment and facilitate development of a digital sector. This setup has also enabled the emergence of local startups as important providers of digital solutions in the agricultural sector. Present study however has identified few gaps in the availability of services and areas for future development in these countries. There is an urgent need to put emphasis on the development of Agricultural Service Providers (ASP) in Burundi, Finance and Crop insurance in Ghana, and crop insurance in Rwanda, Nigeria and Burundi. In addition, financial services in DRC also needs to be improved. Several constraints (such as language, cost of services, digital literacy, local capacity) continue to hinder the development of the sector and the equitable distribution of its benefits among different population groups. The public extension system faces challenges in terms of its coverage and the capacities of its agents in the use of digital technologies. It is therefore, of utmost importance to work on digital literacy, focusing on addressing the existing gaps in terms of gender and age groups, as well as designing mechanisms that can be adapted to the needs of users.

Development of digital innovations do not always involve the producers in the innovation process. This often leads to resistance in adoption of the technology by producers. This synthesis paper highlights the diverse needs and challenges faced by three key user groups of digital agro-climatic services: farmers, service providers, and policymakers. Each group requires tailored approaches to improve adoption and impact. A Human-Centered Design (HCD) approach offers a potential solution by directly involving users in the development of digital tools. For farmers, co-designed tools can focus on ease of use, local languages, and bundled services that address agronomic and financial needs. For service providers, HCD can facilitate the integration of climate data into business models, with targeted training and capacity-building. For policymakers, HCD can enhance data sharing, collaboration, and decision-making through well-designed digital platforms and tailored capacity-building efforts. By centering solutions around users' needs, HCD can significantly improve the accessibility, usability, and effectiveness of climate and agronomic digital advisory services Across all six countries, data harmonization and management remain significant challenges for the effective implementation of digital agricultural advisory services. While countries like Rwanda and Ghana have begun to establish frameworks and initiatives for better data management, the overall landscape is characterized by fragmentation, limited interoperability, and insufficient integration of data across platforms. Standardizing data collection and harmonization would be crucial steps toward enhancing the functionality and scalability of digital services in the region.

REFERENCES

Abdulai, A.-R., KC, K. B., & Fraser, E. (2022). What factors influence the likelihood of rural farmer participation in digital agricultural services? experience from smallholder digitalization in Northern Ghana. Outlook on Agriculture. https://doi.org/10.1177/00307270221144641

Awolala, D. O., Mutemi, J., Adefisan, E., Antwi-Agyei, P., & Taylor, A. (2022). Profiling User Needs for Weather and Climate Information in Fostering Drought Risk Preparedness in Central-Southern Nigeria. Frontiers in Climate, 4, 40. https://doi.org/10.3389/FCLIM.2022.787605/BIBTEX

Bal, S.K., and Sarath Chandran, M.A. (2021). Minimizing Weather-Related Risks in Agriculture Through Agromet Advisory Services in India. In: Hebsale Mallappa, V.K., Shirur, M. (eds) Climate Change and Resilient Food Systems. Springer, Singapore. https://doi.org/10.1007/978-981-33-4538-6_9

Clarkson, G., Dorward, P., Kagabo, D., & Nsengiyumva, G. (2017). Climate Services for Agriculture in Rwanda: Initial findings from PICSA monitoring and evaluation, October 2017 - Rwanda | ReliefWeb (CCAFS Info Note).

Coulibaly, J. Y., Birachi, E. A., Kagabo, D. M., Mutua, M. M., & Hansen, J. (2017). Climate services for agriculture in Rwanda: What farmers know about climate information services in Rwanda (CCAFS Info Note). CGIAR Research Program on Climate Change, Agriculture and Food Security.

CTA. (2019). Rapport sur la numérisation de l’agriculture africaine 2018–2019. CTA.

Daum, T., Villalba, R., Anidi, O., Mayienga, S. M., Gupta, S., & Birner, R. (2021). Uber for tractors? Opportunities and challenges of digital tools for tractor hire in India and Nigeria. World Development, 144, 105480. https://doi.org/10.1016/J.WORLDDEV.2021.105480

Dissanayeke, U.I. *et al.* (2021). An Agro-Met Advisory System to Reduce the Climate Change Risks and Enhance Disaster Risk Resilience of Farmers in Dry and Intermediate Zones of Sri Lanka. In: Amaratunga, D., Haigh, R., Dias, N. (eds) Multi-Hazard Early Warning and Disaster Risks. Springer, Cham. https://doi.org/10.1007/978-3-030-73003-1_38

Donat, M., Lowry, A., Alexander, L. *et al.* 2016. More extreme precipitation in the world's dry and wet regions. *Nature Clim Change* **6**, 508–513 (2016). https://doi.org/10.1038/nclimate2941

Downie, R. (2017). Growing the Agriculture Sector in Nigeria. Growing the Agriculture Sector in Nigeria (csis.org)

FAO, & ITU. (2022). Status of digital agriculture in 47 Sub-Saharian African countries. https://doi.org/10.4060/cb7943en

ILO. (2021). ILOSTAT. International Labour Organization. https://ilostat.ilo.org/

ITA (2022). Democratic Republic of the Congo – Agriculture. https://www.trade.gov/country-commercial-guides/democratic-republic-congo-agriculture

ITU. (2021). Data and analytics: taking the pulse of the information society. International Telecommunication Union. https://www.itu.int/itu-d/sites/statistics/

Jost, C., Kyazze, F., Naab, J., Neelormi, S., Kinyangi, J., Zougmore, R., Aggarwal, P., Bhatta, G., Chaudhury, M., Tapio-Bistrom, M. L., Nelson, S., & Kristjanson, P. (2015). Understanding gender dimensions of agriculture and climate change in smallholder farming communities. Climate and Development, 8(2), 133–144.

Kropff, W., Jiménez, D., Molero, A., Smith, G., Mehrabi, Z., Megan, M., Koo, J., Reynolds, M. P., Ramirez-Villegas, J., Rupavatharam, S., Etten, J. van, Ortiz-Crespo, B., Dhar Burra, D., Biradar, C. M., Tinzaara, W., Florey, C., Manners, R., Gardeazabal Monsalve, A., Pypers, P., … Davis, K. (2021). CGIAR's role in digital extension services. https://hdl.handle.net/10568/114842

Loukos, P., & Javed, A. (2018). Opportunities in agricultural value chain digitisation Learnings from Ghana. www.gsma.com/

Loukou, A. F. (2012). La diffusion de l'Internet en Côte d'Ivoire. Obstacles et implications. Netcom. Réseaux, communication et territoires, (26-3/4), 307-328.

Lozanova, Y., Maddens, S., Sundberg, N., & Prado-Wagener, C. (2022). Global ICT Regulatory Outlook 2020 - Pointing the way forward to collaborative regulation. itu.int/dms_pub/itu-d/opb/pref/D-PREF-BB.REG_OUT01-2020-PDF-E.pdf

Mbizi, R., Sifile, O., & Mabvure, T. J. (2022). Commercial agriculture finance in Zimbabwe. Annals of Social and Behavioural Sciences, 4(1). https://journals.cut.ac.zw/index.php/asbsj/article/view/44

McCampbell, M., Schumann, C., & Klerkx, L. (2022). Good intentions in complex realities: Challenges for designing responsibly in digital agriculture in low-income countries. Sociologia Ruralis, 62(2), 279–304.

McCampbell, Mariette, Schut, M., Van den Bergh, I., van Schagen, B., Vanlauwe, B., Blomme, G., Gaidashova, S., Njukwe, E., & Leeuwis, C. (2018). Xanthomonas Wilt of Banana (BXW) in Central Africa: Opportunities, challenges, and pathways for citizen science and ICT-based control and prevention strategies. *NJAS: Impact in Agricultural and Life Sciences*, *86–87*, 89–100. https://doi.org/10.1016/J.NJAS.2018.03.002

Monerie, PA., Pohl, B. & Gaetani, M. 2021. The fast response of Sahel precipitation to climate change allows effective mitigation action. *npj Clim Atmos Sci* **4**, 24 (2021). https://doi.org/10.1038/s41612-021-00179-6

Nahayo, L., Nsengiyumva, J. B., Mupenzi, C., Mind'je, R., & Nyesheja, E. M. (2019). Climate Change Vulnerability in Rwanda, East Africa. International Journal of TAFS-WCA REPORT DECEMBER 2023 43 Geography and Geology, 8(1), 1–9

Naswem, A., & Ejembi, S. (2017). Reviving Agricultural Extension for Effective Transition from Subsistence to Commercial Agriculture in Nigeria. Journal of Rural Social Sciences, 32(1). https://egrove.olemiss.edu/jrss/vol32/iss1/2

Nel, J., Msengezi, C., Lokers, R. M., Miguel Ayala, L., Addison, C. M., Janssen, S. J. C., & Croque, S. (2019). Policy discussion document: Towards open data for agricultural transformation in Ghana. Ministry of Food and Agriculture. https://doi.org/10.3/JQUERY-UI.JS

Nyarko, D. A., & Kozári, J. (2021). Information and communication technologies (ICTs) usage among agricultural extension officers and its impact on extension delivery in Ghana. *Journal of the Saudi Society of Agricultural Sciences*, *20*(3), 164-172. https://doi.org/10.1016/J.JSSAS.2021.01.002

Nyasimi, M., Radeny, M., & Hansen, J. W. (2016). Review of Climate Service Needs and Opportunities in Rwanda (No. 180).

Ouedraogo, A., Egyir, I. S., Ouedraogo, M., & Jatoe, J. B. D. (2022). Farmers' Demand for Climate Information Services: A Systematic Review. Sustainability, 14(15), 9025

Oyinbo, O., Chamberlin, J., & Maertens, M. (2020). Design of Digital Agricultural Extension Tools: Perspectives from Extension Agents in Nigeria. Journal of Agricultural Economics, 71(3), 798–815.

Partey, S. T., Dakorah, A. D., Zougmoré, R. B., Ouédraogo, M., Nyasimi, M., Nikoi, G. K., & Huyer, S. (2020). Gender and climate risk management: evidence of climate information use in Ghana. Climatic Change, 158(1), 61–75.

Pauw, K. (2022). A review of Ghana's planting for food and jobs program: implementation, impacts, benefits, and costs. Food Security, 14(5), 1321–1335.

Priebe, J. (2022). Data-driven advisory services for climate-smart smallholder agriculture. www.gsma.com

Rathore, L.S., Bhowmik, S.K.R., Chattopadhyay, N. (2011). Integrated Agrometeorological Advisory Services in India. In: Attri, S., Rathore, L., Sivakumar, M., Dash, S. (eds) Challenges and Opportunities in Agrometeorology. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-19360-6_14

Steinke, J.; Ortiz Crespo, B.; Bunn, C.; Van Etten, J.; Jimenez, D.; Le, T.T.; Manners, R.; Muller, A.; Nguyen, P.M.; Ogunsamni, T.; Schumann, C.; Simiyu, M..; Sotelo, S.; Talsma, T.; Zapata, E. (2024) Error 404, farmer not found: Why agricultural information services must consider how smallholders use their phones. Working Paper. Montpellier (France) CGIAR Initiative on Digital Innovation. 8 p.

Statista, 2023. https://www.statista.com/statistics/1121246/population-in-africa-by-country/#:~:text=Nigeria%20has%20the%20largest%20population,Africa%2C%20reaching%20102%20million%20people.

Terefe, B., Oppong-Mensah, B., Siemah, P., Kpodoviah, L., Addy, P., & Davis, T. (2022). Gender and Rural Advisory Services Assessment in Ghana. In *CABI*. https://www.cabi.org/cabi-publications/gender-and-rural-advisory-services-assessment-in-ghana/

The World Bank Group. (2021). Climate Risk Country Profile: Congo, Democratic Republic. 15883-WB_Congo, Democratic Republic Country Profile-WEB.pdf (worldbank.org)

The World Bank Group. (2021). Ghana Climate Risk Country Profile. 15857-WB_Ghana Country Profile-WEB.pdf (worldbank.org)

The World Bank Group. (2021). Nigeria Climate Risk Profile. 15918-WB_Nigeria Country Profile-WEB.pdf (worldbank.org)

The World Bank Group. (2021). Rwanda Climate Risk Profile. 15970-WB_Rwanda Country Profile-WEB.pdf (worldbank.org)

The World Bank Group. (2021). Rwanda Climate Risk Profile. 15970-WB_Rwanda Country Profile-WEB.pdf (worldbank.org)

The World Bank Group. (2022). Cote-d'Ivoire Country profile. https://data.worldbank.org/country/cote-divoire?view=chartThe

University of Notre Dame. (2021). *Notre Dame Global Adaptation Initiative Index* . The Notre Dame Global Adaptation Initiative. https://gain.nd.edu/our-work/country-index/

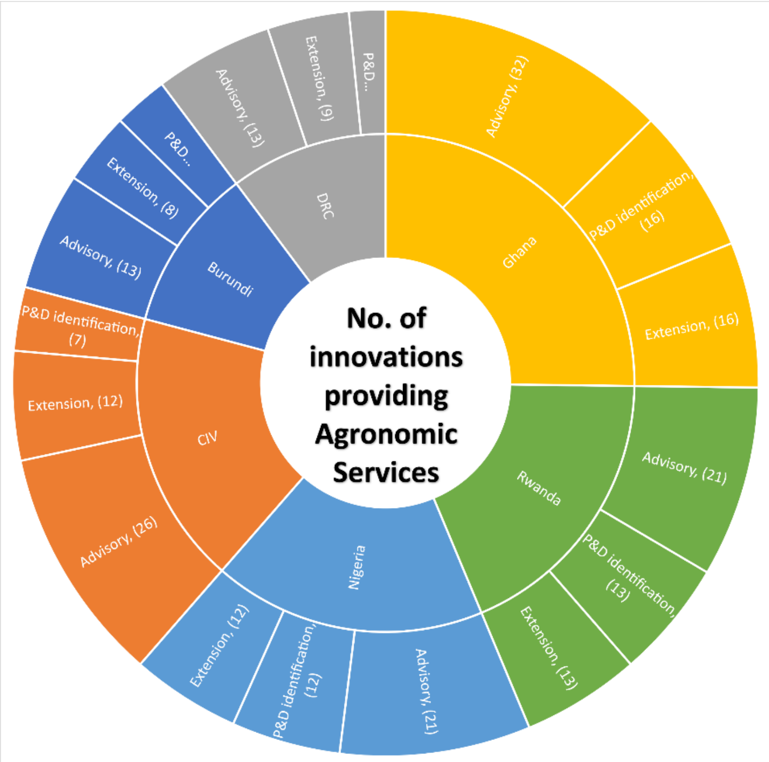
USAID. (2017). Climate Change Risk Profile - Ghana. Climate Change Adaptation, Thought Leadership and Assessments (ATLAS) Task. https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID_Cli mate Change Risk Profile - Ghana.pdf

World Economic Forum. (2020). Global Competitiveness Report Special Edition 2020: How Countries are Performing on the Road to Recovery.

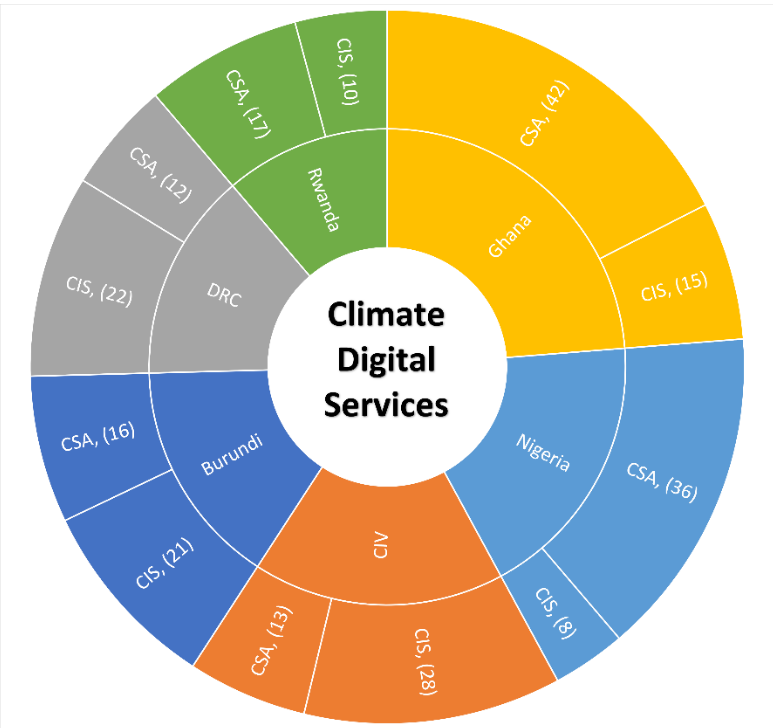
World Economic Forum. (2022). Global Gender Gap Report 2022. Global Gender Gap Report 2022 | World Economic Forum (weforum.org)

ANNEXURE 1. Supplementary Figures

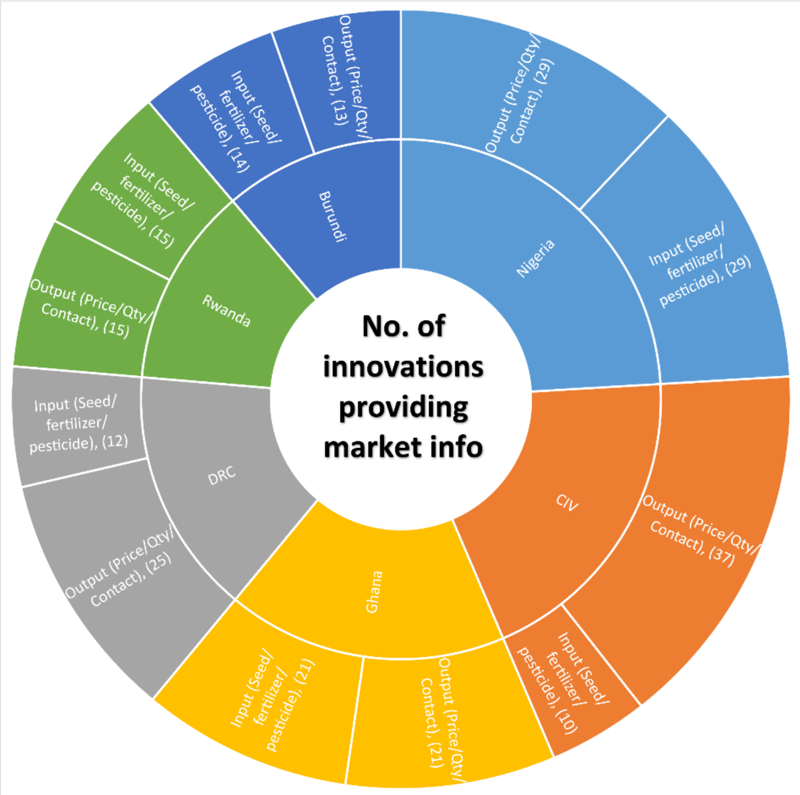
Supplementary Figure 1. Distribution of number of innovations providing information related to agronomic services



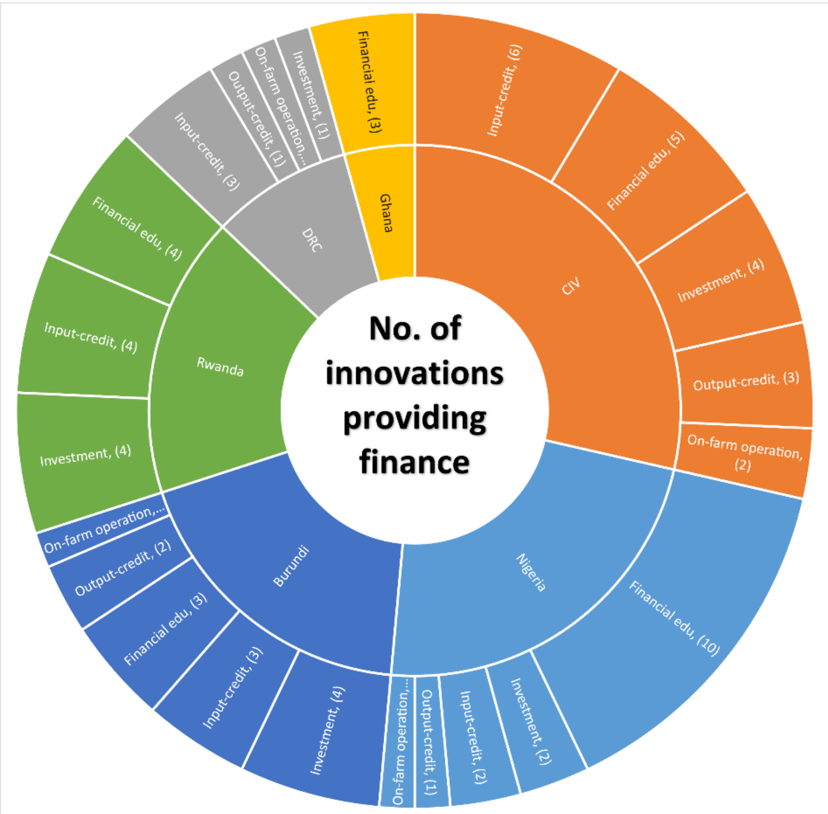
Supplementary Figure 2. Distribution of number of innovations providing Digital Climate solutions in six countries



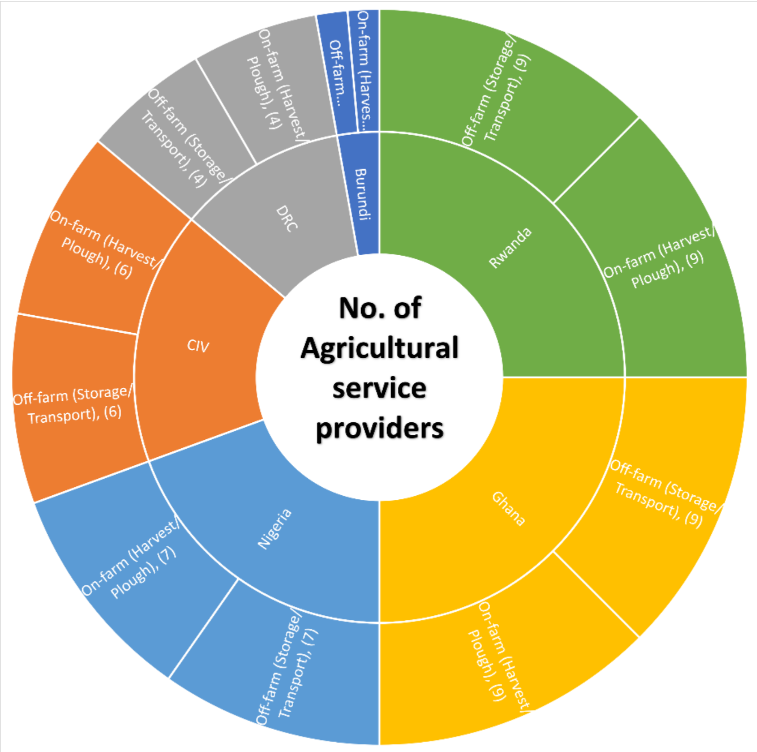
Supplementary Figure 3. Distribution of number of innovations providing market information in the six countries



Supplementary Figure 4. Distribution of number of innovations providing finance in the six countries



Supplementary Figure 5. Distribution of number of innovations identified as agricultural service provider in the six countries



Supplementary Figure 6. Distribution of number of innovations providing crop insurance to different risks in the six countries