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International Center for Tropical Agriculture

CGIAR
Platform for Big Data in Agriculture

Digital Agriculture Profile • Rwanda


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HIGHLIGHTS

Agriculture employs 66.5% of Rwanda's working population and contributes 29% of its Gross National Product.

Rwanda is a small, landlocked, hilly country challenged by land degradation, soil erosion, and land use distribution issues. Poor farming techniques, inefficient production practices, and high dependence on rainfall contribute to persistently low productivity.

Access to and use of digital technologies in Rwanda has grown significantly over the last decade as a result of strong policy support. Remaining challenges include relatively high connection costs, limited infrastructure, and digital illiteracy – especially in the rural areas.

Drones, satellites, GIS[1], SMS/IVR[2] systems, weather stations, database technologies, and advanced analytics are some of the most promising technologies for providing solutions to the key challenges Rwandan agriculture faces.

The private industry, public sector, non-profit organizations, and international community all have important and distinct roles to play in creating sustainable digital agricultural solutions in Rwanda.

1 Geographic Information System.
2 Short message service / interactive voice response.

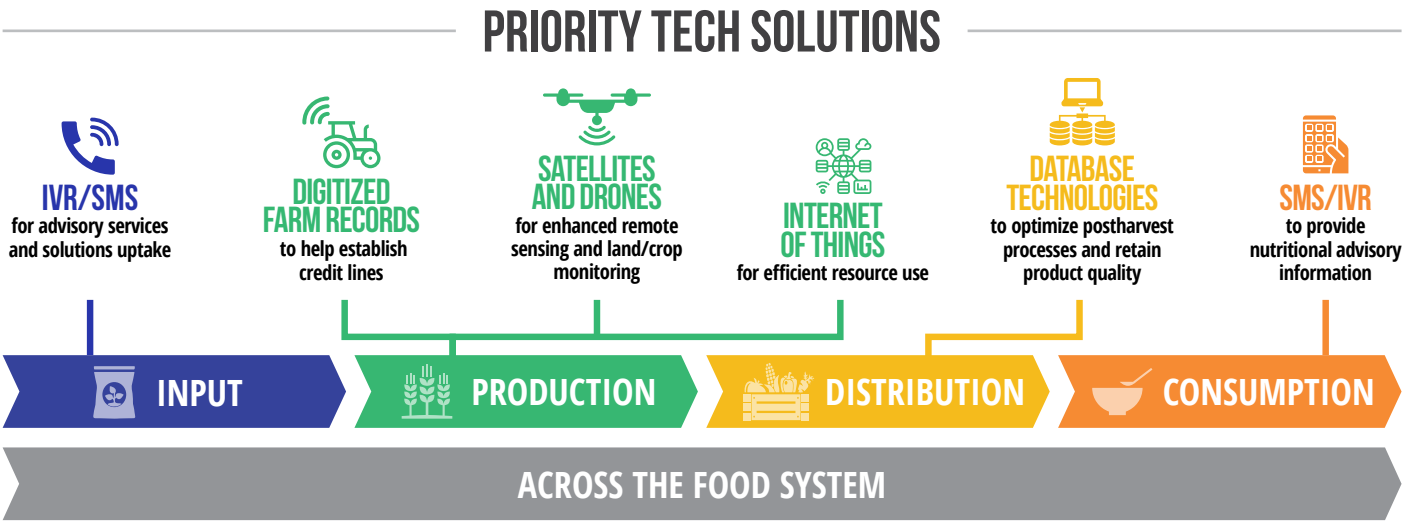
18% OF RURAL RWANDANS HAVE ELECTRICITY

IN RWANDA **60%** OF MEN AND **38%** OF WOMEN OWN A MOBILE PHONE

52% OF THE POPULATION USES THE INTERNET

APPROXIMATELY **27%** OF THE POPULATION HAS MOBILE BROADBAND SUBSCRIPTION;
ONLY **0.2%** HAS A FIXED BROADBAND SUBSCRIPTION

RWANDA HAS AN AVERAGE INTERNET SPEED OF **7689.3Kbps**
THE SECOND FASTEST IN AFRICA



Introduction

Agriculture is at the crux of the Rwandan economy. It accounts for 29% of the total GDP,[3] and 66.5% of the working population is engaged in agriculture and related sectors.[4] This makes agriculture the largest employment sector in Rwanda, and the second largest sectoral contributor to the GDP behind Services, a broad sector that includes government.

Despite their huge contribution, the 3.9 million farmers in Rwanda[5] face various persistent challenges. These include land degradation, soil erosion, land use issues, and land distribution problems. Producers also struggle with an overdependence on rain-fed production systems, inefficient farming practices, poor production techniques, and low post-harvest processing and value-addition capacity. These issues imply low productivity and high vulnerability to climate variability and shocks.[6] Limited access to decision support tools and innovative technologies to support farmers and other value chain actors compounds this vulnerability.

The emergence of digital agriculture provides a new portfolio of potential solutions to address these challenges. Digital agriculture is the use of new and advanced technologies, integrated into one system, to enable farmers and other stakeholders to improve their products and processes. Integrating digital solutions into agriculture can improve efficiency by decreasing financial and labor costs, providing information to support management decisions, increasing product quantity and/or quality, reducing losses, and ensuring effective and sustainable use of resources. Ultimately, the transition to digital agriculture presents a unique opportunity to spur sustainable economic growth and development by addressing agriculture's biggest challenges.

The Digital Agriculture Profiles are knowledge and policy advisory products of the African Development Bank's Digital Agriculture Flagship. The profiles for Côte d'Ivoire, South Africa and Rwanda join a series of similar inter-organizational guides, first conceived by the World Bank which also include countries such as Argentina, Grenada, Turkey, Kenya and Vietnam. This Digital Agriculture Profile for Rwanda leverages the expertise of stakeholders to evaluate the current landscape of digital agriculture in Rwanda, including its key players across value chains, the main barriers they face, and the potential to overcome these barriers through the adoption of innovative technologies. In identifying and prioritizing these technologies, we aim to support investors and implementers in maximizing their impact by focusing on the opportunities of highest potential. Once enabling factors are identified and understood, the mainstreaming of digital agriculture in Rwanda can begin in earnest.

National Context

Economic relevance of agriculture

Agriculture has played a crucial role in Rwanda's growth and poverty reduction. It is the mainstay of the economy,[7]

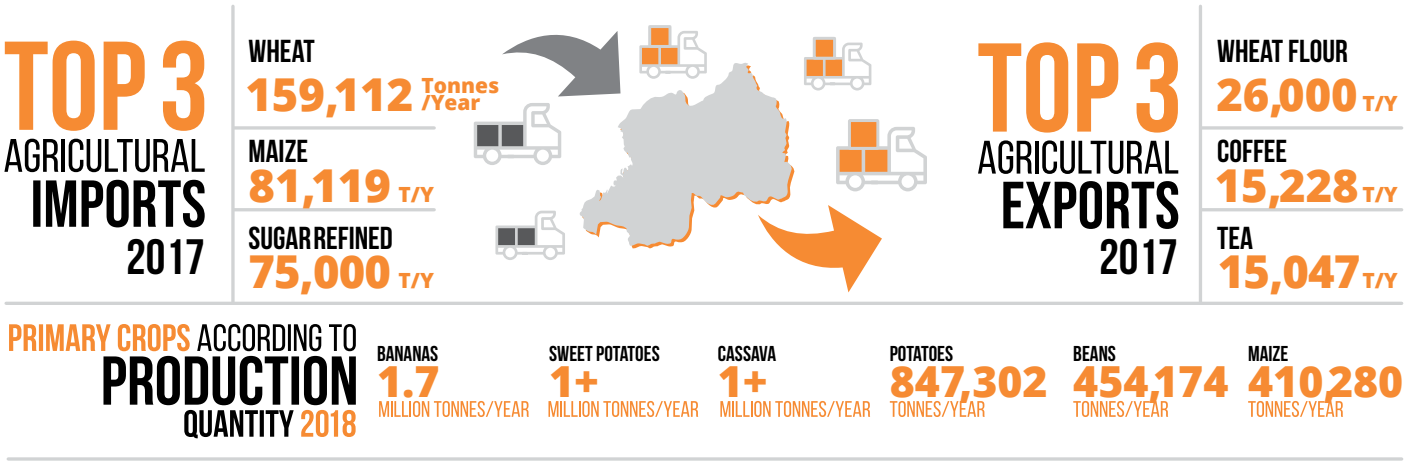
3 Data Bank, "Rwanda."

4 Human Development Reports, "Rwanda."

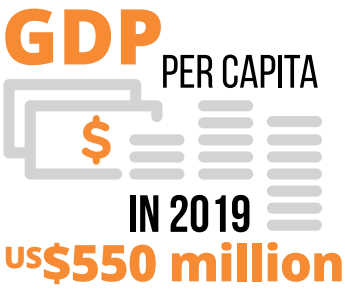
5 National Institute of Statistics Rwanda, "Agricultural Household Survey."

6 FAO, "Rwanda at a Glance."

7 FAO.



which has been growing at the rate of 7% annually since 2014. Agriculture accounted for 63% of the foreign exchange earnings and supplied 90% of the national food supply as of 2013.[8] Agriculture sector contributions to GDP averaged US$ 393.6 million from 2006 to 2019. The sectoral contribution to GDP hit a record low of US$ 258 million in the first quarter of 2006, and has been increasingly steadily since then, reaching a record high of US$ 550 million in the first quarter of 2019.[9]



Wheat flour, coffee and tea are major export commodities,[10] along with avocado, tomato, cabbage, leek, pyrethrum, animal skins, and value-added products such as canned tomatoes, honey, French beans, passion fruit, macadamia, and mushrooms. Rwanda exports live animals, unprocessed meat, and dairy products across the border to the Democratic Republic of the Congo. Rwanda is also increasingly connected to Europe and Asia via domestic and international air carriers, and this has increased the country's fresh product exports.

Agriculture is a priority sector in Rwanda's Vision 2050 national development strategy. The government aims to replace subsistence farming with a fully monetized and technology-intensive commercial agriculture and agro-processing system by 2050.[11]

Agricultural production systems

Rwanda's overall high altitude and temperature allows year-round cultivation. The western areas have relatively lower altitudes, warmer temperatures, and less precipitation. Approximately 47% of the total land area, or 1,151,700 hectares, is arable.[12] The first production season runs from September to January, and the second from February to June. In the marshlands, where water is abundant, there is also a third agricultural season for the cultivation of rice and vegetables. Plantains, cassava, potatoes, sweet potatoes, maize, and beans are the most widely produced crops.[13] Value addition, which may include cleaning, preservation, sorting, packaging, canning, and labelling, is carried out on some produce in rural areas.

People, livelihoods, and agriculture

At nearly 499 people/km^2, Rwanda has the highest population density on continental Africa and the 23rd highest population density in the world. Notably, 16 of the top 22 most densely populated countries are island nations.[14] The population is young and primarily rural. The 2019 population was estimated at 12.63 million. Annual population growth sits around the

8 The World Bank, "Agricultural Development in Rwanda."

9 National Institute of Statistics Rwanda, "GDP National Accounts (First Quarter 2019)."

10 The World Bank, "Rwanda Economic Update."

11 World Bank, "Future Drivers of Growth in Rwanda: Innovation, Integration, Agglomeration, and Competition."

12 The World Bank, "Arable Land (% of Land Area) - Rwanda."

13 FAO, "Rwanda at a Glance."

14 The World Bank, "Population Density (People per Sq. Km of Land Area) - Rwanda."

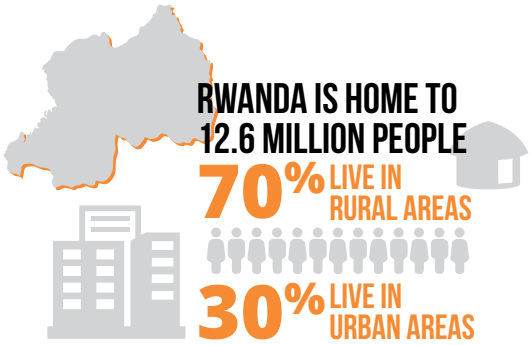
Sub-Saharan African average of 2.7% annually, versus Niger (3.8%) and Mauritius (0.1%).[15] Rural inhabitants comprised approximately 70% of the total population in 2016.[16] About 56% of the population was below the international poverty line of US$1.90 / day as of 2016.[17]

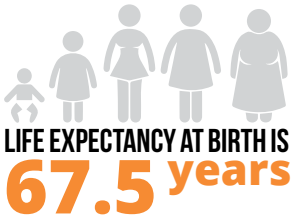
Rwanda ranked 158/189 on the Human Development Index with a score of 0.524 as of 2017; this represents a substantial increase from 0.250 in 1990.[18] The country also ranked 158/189 on the Gender Development Index as of 2017.[19] Since 1990, Rwanda's average life expectancy at birth has increased nearly 200%, from 34.2 to 67.5 years. The mean years of schooling has increased by 2.3 years, and expected years of schooling by 5.5 years. During the same time period, Rwanda's GNI[20] per capita increased by 108.4%. Skilled workers form about 6.8% of the total population.[21] Approximately 18% of rural and 72% of urban dwellers have electricity—an average of about 34% across the country.[22]

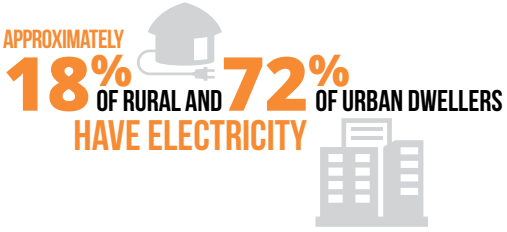
Challenges in the agricultural sector

The Rwandan agricultural sector has seen significant achievements and growth. Nevertheless, a multitude of poverty-related challenges remain in terms of smallholder farmers. Nearly 80% of the rural population is engaged in subsistence farming, and the average landholding is less than 0.6 hectares.[23] This persistent land shortage calls for diversification of rural income opportunities as well significant agricultural intensification.

These dual goals will be achieved via productivity-enhancing technology; raising stakeholder capacities for production, processing, and value addition; innovating solutions for pest and disease control; and improving irrigation, transport, and postharvest infrastructure and facilities. Additionally, there is a need to stabilize market pricing and the cost of inputs (including labor and transportation); integrate postharvest value chains; and ensure stakeholder access to knowledge, financial, and advisory services.[24] Significant financial investment and robust institutional capacity are prerequisites to such sectoral transformations.







15 World Bank, "Population Growth (Annual %) - Sub-Saharan Africa."

16 The World Bank, "Population, Total - Rwanda."

17 World Bank, "Poverty Headcount Ratio at $1.90 a Day (2011 PPP) (% of Population) - Rwanda."

18 Human Development Reports, "Rwanda."

19 UNDP, "Gender Development Index."

20 Gross National Income

21 Human Development Reports, "Rwanda."

22 Power Africa, "Rwanda"; The World Bank, "Access to Electricity (% of Population)."

23 FAO, "Country Programming Framework for Rwanda."

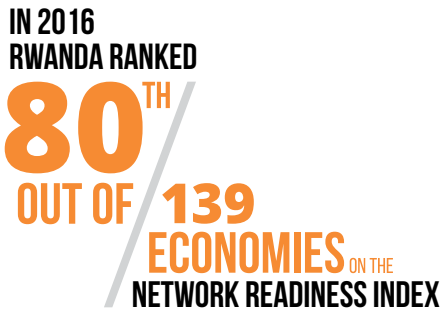
24 FAO.

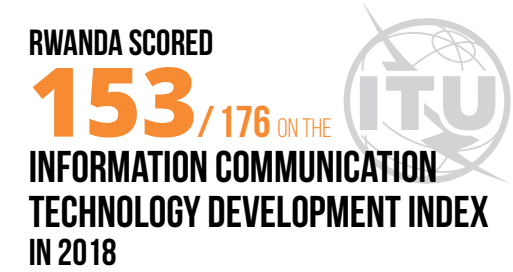
Current landscape of digital tools and policies

The digital technologies base, including its application for creating solutions to agriculture challenges in Rwanda, is nascent and quite promising.

Digital infrastructure, availability and access

Rwanda ranked 80/139 on the Network Readiness Index of 2016, moving up three places from the year prior, primarily due to the increasing government focus on a digital agenda.[25] It is ranked behind only South Africa and Seychelles in the Africa region. The Telecommunication Infrastructure Index scored Rwanda 0.4590, putting it behind eight other African countries; the regional leader, Mauritius, scored 0.6678. The e-Government Development Index ranked Rwanda 120/193 in 2018, 18 places higher than its 2016 ranking. The country also moved up 32 places on the e-Participation Index in the same time period to 57/193.[26] The country's Information Communication Technology Development Index score also improved marginally—from 2.10 in 2016 to 2.18 in 2017, although it lost two places in the ranking, down to 153/176, as a result of other countries' relatively larger strides.[27] This suggests untapped potential in Rwanda's moves toward digital readiness. For example, 92% of the country is covered by 3G fiberoptic cable, 95% of the country has 4G LTE coverage,[28] and plans have been laid to begin developing a 5G network by the end of 2019.[29] Even so, as of 2018, only 52% of the population used the Internet.[30] There are also significant gender disparities in technology usage: 60% of men own a mobile phone versus 38% of women. There are over 9 million active mobile phone subscriptions, with many people owning more than one subscription. Approximately 27% of the population has a mobile broadband subscription, while just 0.17% has a fixed broadband subscription.[31] The low percentage of fixed broadband connections can be attributed to high costs: Rwanda ranked 136/139 countries in terms of affordability of fixed broadband Internet.[32] The biggest telecommunications network providers in the country as of June 2019 were MTN Rwanda and Airtel/Tigo, controlling 54% and 46% of the active mobile phone subscriptions, respectively.[33]





End-user diversity and demand

Digital agriculture end users may be generally grouped into four hubs. Each hub has unique resources and needs in terms of digital agriculture, and each hub faces unique challenges for which digital agriculture could offer solutions. The hubs are not mutually exclusive; any given individual may function simultaneously within more than one.

The **Input Hub** includes all actors providing agricultural inputs such as seeds, feeds, agrochemicals, machinery, and finance. The key challenges confronting stakeholders in this hub are limited access to finance services and lack of risk mitigation strategies that can improve credit access. There is also a general lack of an entrepreneurial mindset and low digital literacy among actors within the hub.

25 Global Information Technology Report, "Rwanda."

26 e-Government Knowledge Base, "Country Information: Rwanda."

27 International Telecommunications Union, "Executive Summary: Rwanda."

28 Ministry of ICT and Innovation, "Rwanda's Digital Transformation."

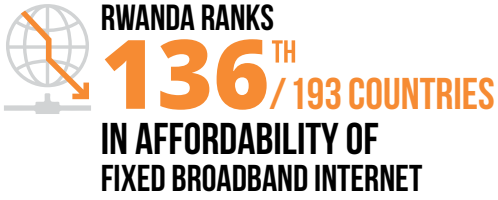
29 Editor RBD, "Rwanda Eyes 5G Internet by End of 2019"; Africa, "Is Rwanda Ready for 5G?"

30 GSMA Intelligence, "Data by Country."

31 RIA, "After Access Household and Individual ICT Survey."

32 Global Information Technology Report, "Rwanda."

33 Rwanda Utilities Regulatory Authority, "Statistics Report for Telecom, Media, and Postal Sector as of the First Quarter of the Year 2019."



The **Production Hub** fundamentally consists of farmers and livestock keepers. Producers in Rwanda contend with a general lack of or inadequate access to decision support tools that can help them to better manage their farms and improve their productivity. Additionally, producers struggle with limited access to farm mechanization that could raise their production, improve their resource use efficiency, and drastically reduce labor time and drudgery. Limited market access, low traceability within market channels, and low capacity for accessing finance are also key challenges.

The **Distribution Hub** consists of all actors in the value chain between farmers and consumers, including traders, transporters, and processors. The main challenge of this hub is poor feeder roads connecting rural communities to urban centers. Actors also face limited access to finance services and postharvest facilities, which reduce postharvest losses, improve the shelf life of agricultural products, and improve seasonal product profitability.

The **Consumer Hub** comprises the consumers of both raw and processed agricultural—in effect, the entire population. One of the key challenges facing all stakeholders in the consumer hub is a limited access to nutritional and dietary advisory information. Purchasing power – a factor of income level – is a limiting factor. Rural consumers, some of whom are producers themselves, typically have lower income levels and purchasing power compared to their urban counterparts. Other challenges to this hub include seasonality and the social dimensions of food consumption, which are influenced by traditions, culture, and mindset.

A group of in-country experts convened in a workshop as part of the development of this Digital Agriculture Profile. The workshop participants estimated that 75% of actors across all hubs have access to at least basic mobile phone services. Over the course of the next 5 years, they expect that to increase to 90% for the Producer Hub, 95% for the Input and Distribution Hubs, 85% for rural Consumer Hub actors, and 100% for urban constituents of the Consumer Hub. The group estimated that 20% of producers have access to weather, pest, and disease forecasts, and they expect that this will rise to 50% over the next 5 years.

Several cross-cutting challenges arise for all Hubs. There is very limited access to financial services and risk mitigation mechanisms to support innovation because agriculture is perceived as a high-risk sector. Actors across all hubs lack sufficient access to timely knowledge and advisory information to support decision-making. Lastly, while traceability of food and agricultural products is become increasingly important in terms of public health, nutrition, and consumer preferences, traceability mechanisms remain largely undeveloped.

Institutions and policies for Digital Agriculture

Digital agricultural solutions have received strong policy underpinnings via the Government of Rwanda's National ICT4RAg[34] Strategy 2016-2020 policy. This strategy engages a multi-sectoral approach led by the Ministry of Agriculture and supported by other ministries and agencies of the government of Rwanda. Its overall objective is to significantly improve productivity and expand the agricultural sector's job creation capacity through the digitization of agricultural lending, input supplies, subsidies, and advisory services.[35] Within that framework, the definition of digital agriculture and the array of technologies it entails is still evolving.

The 2016-2020 National ICT4RAg Strategy integrates with and extends earlier strategies, such as the Rwanda Strategic Plan for Agriculture Transformation Phase 3, and is closely aligned with the National ICT[36] Strategy and National Information & Communication Infrastructure Plan 2020 (also known as NICI IV or the SMART Rwanda Master Plan). The NICI Plan was first launched in 2001 and is now in its fourth iteration. Much of the policy framework guiding the earlier development of digital technologies in Rwanda rested on NICI I-III. These policies aimed to build institutional and policy structures for digital technology growth (NICI I); to create wealth, generate employment, and reduce poverty (NICI II); and to deliver digital technology services via targeted interventions at the local level (NICI III). The NICI IV focuses on consolidating the gains of NICI I-III into Rwanda's Vision 2020 via 7 pillars, the first of which is agriculture, and 3 enablers, among which is ICT Capability and Capacity. The National ICT4RAg Strategy, then, builds on NICI IV to foster an enabling environment for the

34 information communication technologies for rural agriculture

35 Republic of Rwanda, "National ICT4 Ag Strategy (2016 -2020)."

36 information communication technology

uptake of digital agriculture, and to integrate and build on the gains of NICI I-IV within agricultural value chains and at the community level.

The government also encourages the development of digital technologies for agriculture by supporting individuals, especially young people, who are developing digital solutions in alignment with the objectives of its strategy. For example, the K-Lab was created with the support of the government of Rwanda to promote, facilitate, and support the development of innovative digital solutions by bringing together a community of digital technology innovators, entrepreneurs, and mentors.[37] It is housed in the Rwanda Information Society Authority. Some targeted governmental digital agriculture programs are also led by the Rwanda Agriculture and Animal Resources Board.[38]

International development organizations and private businesses have also shown strong support for digital agriculture development in Rwanda. Organizations such as the FAO[39], One Acre Fund, African Development Bank, World Bank, ICRAF[40], IITA[41], and private entities such as the Bank of Kigali (through its BK TecHouse) make significant contributions to creating an environment that supports the development and use of digital agriculture technologies in Rwanda via financing, technical expertise, and project piloting.

Digital agricultural services and applications available

The government, development organizations, and the private sector are all quite active and coordinated in creating and supporting digital agricultural innovations in Rwanda. Eight digital agriculture solutions providers are headquartered in Rwanda, and a total of 44 have a presence in the country.[42] Their services include advisory services, market linkages, supply chain management, financial service access, and macro-agriculture intelligence, among others.

The government of Rwanda is an active promoter and enabler in the digital agriculture space. E-Soko, perhaps the best-known digital agriculture service in Rwanda, is a government-supported market linkage platform that collates and provides timely market information to agriculture value chain actors. E-Soko focuses on helping farmers get a fair price for their harvest and earn a living wage from agriculture.

The Ministry of Agriculture also support the Agricultural Management Information System, an information portal through which users can access audio and video agricultural extension materials, reports, research outputs, surveys, and other advisory information. The Ministry of Agriculture and other government institutions use SMS/IVR[43] systems to interface with farmers, share vital information, and get feedback from farmers and other agricultural value chain actors.[44]

International research and development organizations are also piloting projects that mainstream digital technologies in Rwandan agriculture, oftentimes in collaboration with the Ministry of Agriculture and Rwanda Agriculture Board. IITA[45] is using remote sensing and GPS[46] technologies for the surveillance and control of the Banana Xanthomonas Wilt.[47] The One Acre Fund has piloted a farm registration system that runs on USSD[48] technology[49] and enables farmers to register for its products, access micro-credit, manage repayment, and monitor their balance – all from their mobile phones.[50] ICRAF[51] worked with the Ministry of Agriculture to develop the Rwanda Irrigation Master Plan Phase II (2010), which uses GIS[52] mapping tools to determine total suitable land area for irrigation and provide vital decision-making tools for on-farm irrigation across Rwanda.

The private sector is also developing or importing digital agricultural solutions for Rwanda. m-Farm is an application that supports the distribution and management of agricultural inputs. The Smart Nkunganire System, a platform created by the BK TecHouse of the Bank of Kigali in collaboration with Rwanda Agriculture Board, digitizes supply chain management for the agro-input subsidy program of the government of Rwanda.[53] N-Frnds, created in collaboration with the Ministry of Agriculture, is a platform that automates supply chains, conducts analytics, and provides services and processes for farmers. It also verifies farmland information for the provision of subsidies, credits, and insurance.[54]

37 kLab, "Open Space for IT Entrepreneurs."

38 Rwanda Agriculture Board, "Rwanda Agriculture and Animal Resources Development Board."

39 Food and Agricultural Organization of the United Nations

40 The World Agroforestry Centre

41 Institute for International and Tropical Agriculture

42 Tsan et al., "The Digitalisation of African Agriculture Report."

43 short message service / interactive voice response

44 Republic of Rwanda, "National ICT4 Ag Strategy (2016 -2020)."

45 Institute for International and Tropical Agriculture

46 geographic positioning system

47 Adewopo, "Citizen Science and ICT for Advancing the Prevention and Control of Banana Xanthomonas Wilt (BXW) in East and Central Africa."

48 unstructured supplementary service data

49 Tsan et al., "The Digitalisation of African Agriculture Report."

50 Systems Lead, One Acre Fund.

51 The World Agroforestry Centre

52 geographic information system

53 In-country Expert Workshop Representative, BK TecHouse.

54 N-Frnds, "Agriculture."

Challenges for digital agriculture

Rwanda has made significant progress in improving the infrastructure for and access to digital technologies in the last decade, particularly considering the low base from which it started. Nevertheless, key challenges remain in terms of transitioning to an environment that is highly conducive to the adoption of digital agriculture technologies. Digital infrastructure is still an important challenge: although the country has invested massively in building 4G/5G national coverage, last-mile connection remains an issue that inhibits the adoption of digital technologies.[55]

Another key challenge to the development and mainstreaming of digital agriculture in Rwanda is a pervasive lack of access to electricity. Rwandans pay more for electricity than any of their East African Community bloc neighbors--currently 22% more than the next highest national average.[56] This expense is the primary reasons only 34% of Rwandans have electricity access in spite of the country's small geographic area and high population density. In rural areas, where more farmers live, the rate of electricity access plummets to 18%.[57] This rate is quite low relative to Rwanda's Human Development Index score; Guinea and Mali, which rank 175/189 and 182/189 on the Human Development Index, both have higher electricity penetration rates than Rwanda.[58]

Inadequate technical skills, both at the institutional and individual levels, impede the development of digital agriculture innovations.[59] A significant digital technology skills gap calls for long-term training programs and short-term recruitment of international personnel.[60] Andela, for example, is providing training for young Rwandans in software development and computer engineering with the aim of raising technical capacity in the years to come.[61]

Perhaps the biggest challenge to digital agriculture, and one identified by all the hubs at the in-country expert workshop, is that of low digital literacy. Other challenges mentioned during the workshop include limited availability of digitized extension material, the lack of an open data or information sharing culture, the high cost of digital equipment, and limited access to finance for digital agriculture projects.

55 International Telecommunications Union, "Executive Summary: Rwanda."
56 Bimenyimana, Asemota, and Li, "The State of the Power Sector in Rwanda."
57 Power Africa, "Rwanda."
58 Human Development Reports, "Rwanda."
59 Republic of Rwanda, "National ICT4 Ag Strategy (2016 -2020)."
60 International Telecommunications Union, "Executive Summary: Rwanda."
61 Andela, "Apply To The Fellowship."

Enabling Digital Agriculture

An important first step in leveraging digital agriculture to solve real-world problems is identifying the most promising technologies across multiple end user barriers. This enables investors and implementers to focus their efforts on areas of highest impact. Once enabling factors are identified and understood, the mainstreaming of digital agriculture in Rwanda can begin in earnest.

In this analysis, we focus on identifying, for each of the end user hubs, the main challenges confronting the agriculture sector. We then identify, using participatory methods, a set of technologies and associated functions and outcomes. Table 1 shows the results of the technology prioritization across hubs. The prioritized technologies address 13 hub-specific and 3 cross-cutting challenges. Next, each technology was assessed across six dimensions: progress (i.e. current level of use/adoption); current enabling policy; potential (i.e. level of use/adoption and impact); efficiency (in the operation of the food system); equity; and environment. Each of these was assessed using several indicators. The results of the technology identification and assessment are described below, followed by a discussion of the policies, the role of the public and private sector, and the financing options available to support the promotion of the most promising technologies.

Technologies with greatest potential

The main challenges identified for the **Input Hub** were lack of risk mitigation strategies and low awareness and uptake of available solutions. Technologies such as USSD , SMS-IVR systems, and smartphone applications are those with the greatest potential for impact. These technologies will facilitate the provision of timely advisory information, access to finance and insurance, and overall decision support to hub actors. Some of these technologies are already being deployed as pilot projects. Low digital literacy within the hub is the primary limiting factor in terms of these technologies achieving their full potential impact.

Digitized farm records, remote sensing, GPS , drones, satellites, e-wallets, mobile money, e-commerce, digital market platforms, and IoT are some of the key technologies that offer great promise for the **Producer Hub** in Rwanda. These technologies are expected to improve pest and disease control, connect producers to consumers, improve financial services access, increase mechanization, and support producers in the adoption

of smart farming practices. Further research on the impact of these technologies by value chain will enable prioritization of interventions to maximize food system enhancement. Given the excellent enabling policy environment, strong support from the government, and pending nationwide 5G network, these technologies can be expected to proliferate. However, challenges associated with the cost of last-mile connectivity, digital literacy, and technical capacity need to be addressed via coordinated public-private efforts.

Database technologies, smartphones, SMS , satellite, GIS , and digital weighing are the most promising technologies for the **Distribution Hub.** Weather and seasonal forecasts based on satellites and GIS technologies will improve market transport timing and thus reduce costs and losses associated with harvesting and transporting produce in extreme weather. Smartphone apps and SMS can create direct connections between producers and distributors or e-markets. Database and digital weighing technologies will support the effective functioning of warehousing facilities, reducing postharvest losses and increasing product shelf life by standardizing produce weighing and packaging and digitizing records for transparency and easy retrieval. Improved access to financing will be necessary in order for these capital-intensive innovations to enter the mainstream. Policies, laws, and campaigns that foster acceptance of warehouse receipts as short-term credit in the banking system and establish trust and transparency between stakeholders will also be important.

Digital information platforms, SMS/IVR , mobile apps, and barcoding have the greatest potential to provide solutions to some of the key challenges in the **Consumer Hub**. Consumers face limited access to information on pricing, seasonality, nutrition, sourcing, and processing of the products they consume, as well as a dearth of opportunities to provide feedback regarding their needs and preferences. Digital information platforms and SMS/IVR can be used to provide knowledge and feedback. Barcoding technology enables traceability and verification of source and distribution channels. Policies and partnerships with mobile networks can help speed the mainstreaming of some of these technologies. Nevertheless, generating and disseminating a steady flow of digital content will require considerable time, technical expertise, and funding.

Policies to Enable Digital Agriculture

The Rwanda National ICT4RAg Strategy 2016-2020, the NICI-2020 , and the Rwanda Vision 2020 will all expire this year, and the ICT Sector Strategy Plan 2013-2018 has recently expired. This represents a new opportunity for Rwanda to review the policies and plans guiding the development of its digital technologies, and to transition to a broader array of emerging digital technologies that may not necessarily fall within the ICTs spectrum. New policies should consolidate past gains, particularly in terms of infrastructure and policy leadership, while integrating short- and long-term solutions to the key remaining challenges: high cost, low last-mile connectivity, low technical development capacity, and digital literacy issues. In addition, new policies may address and provide explicit guidance for the issues that often face emerging digital technologies, including cyber threats, data rights, data ownership, and data privacy. This entails clarifying the rights and responsibilities of data owners, data users, third-party analytics companies, and other key players in order to foster an environment of responsive laws, systemic trust, and strong political leadership. Lastly, reducing risk for the agriculture sector—and for the providers and users of digital agriculture solutions—will also require policy intervention. While government input subsidies already exist for farmers, the agricultural sector is not yet attractive to banks and lenders. Additional risk mitigation in the form of productivity and profitability will help establish an agricultural sector that is prepared to take on risk and invest in innovative digital solutions.

Potential avenues for the public sector

Across all the hubs, limited access to decision support tools and systems was identified as a key challenge. Decision support tools such as early warning systems, weather forecasting, seasonal predictions, and forecasts for pests and disease are crucial for informed agricultural decision-making. Given the cost of such resources, human resource requirements, and limited ability of end users to pay, at this point in time, these services can most effectively be provided by the public sector, entirely or in cooperation with the private sector and international science organizations. The establishment of such services implies a significant financial investment. In the 2018/2019 fiscal year, 5% of the Rwandan national budget was allocated to agriculture. For the 2019/2020 fiscal year, this figure dropped to 4%, although in real numbers the allocation grew slightly due to growth in the total national budget. A portion of the agricultural allocation can be applied to the use and further development of existing decision support tools. This simultaneously entails preparing farmers for digital transformation by enhancing digital literacy. The next ICT4RAg country-wide strategy should provide for detailed mapping of which value chains currently have

the highest readiness towards digital transformation (measured by extant infrastructure, access, and digital literacy) and will provide high return on investment while simultaneously improving food security. Additionally, as the government has already been taking into account, in these next years it will be even more crucial to focus efforts on ensuring equity in the deployment of digital solutions to help farmers generate higher production values, increase their market access, and improve their livelihoods.

The portion of the agricultural budget dedicated to research and development, technology transfer, and advisory services is equally important. The research, development, and dissemination of innovations is far and away the strongest predictor of agricultural sector growth, accounting for 51% of productivity gains across Sub-Saharan Africa. In the Strategic Plan for Agricultural Transformation III 2013-2017 budget, the total allocation to "research and technology transfer, advisory services, and professionalization of farmers" (which has an element of digital literacy) was 1.15%. Dedicating additional financial and human resources to these elements in future strategies will bring outsized positive impacts to the sector.

The government of Rwanda has already broken ground on developing capacity in entrepreneurship and has helped start-ups through incubators and accelerator models. Knowledge transfer is also facilitated by uncomplicated procedures for foreign companies to work in Rwanda; the country ranks 38th globally on the Ease of Doing Business Index. There is ample opportunity for the government, together with other actors, such as the African Development Bank, to further enhance Rwanda's human resources in digital solutions over the next two years. Human resource development will help ensure sustained growth of digital agricultural solutions far into the future.

Rwanda has built an effective extension system. There is now opportunity to further bolster, diversify, and expand this system through digital innovations. Data analytics, information services, and decision support tools can aid extension agents in rapidly synthesizing data to detect trends and provide the most current information to farmers. Digital solutions vastly improve the speed and efficiency with which agents can communicate with farmers. Building digital literacy at the institutional and individual levels will be crucial to the success of such endeavors.

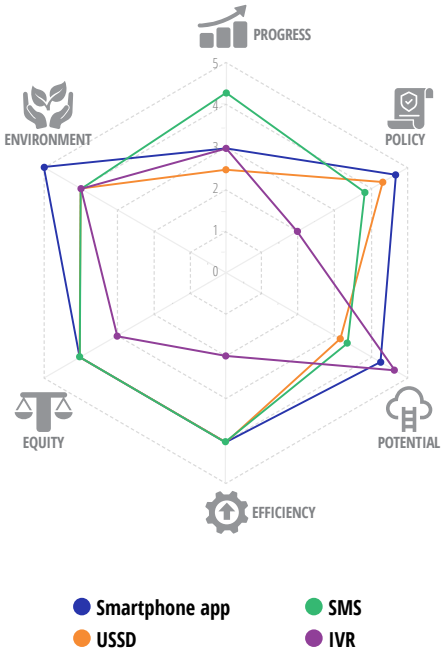
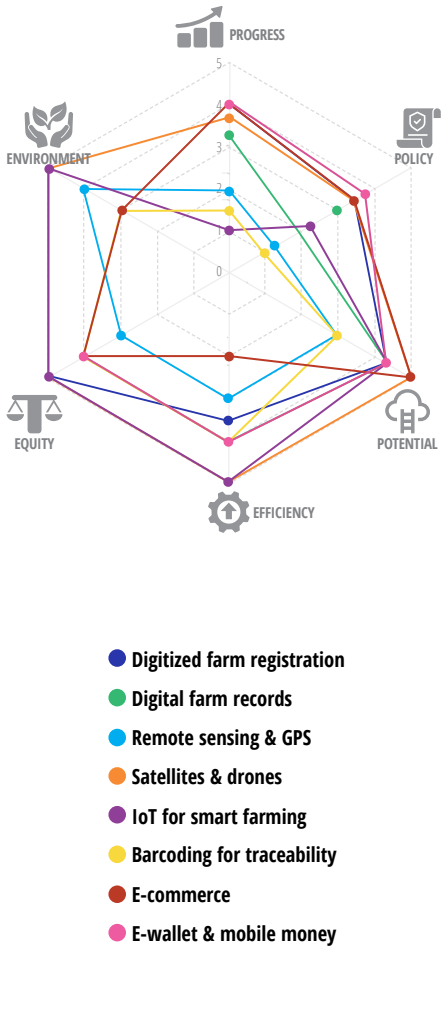
Potential avenues for the private sector

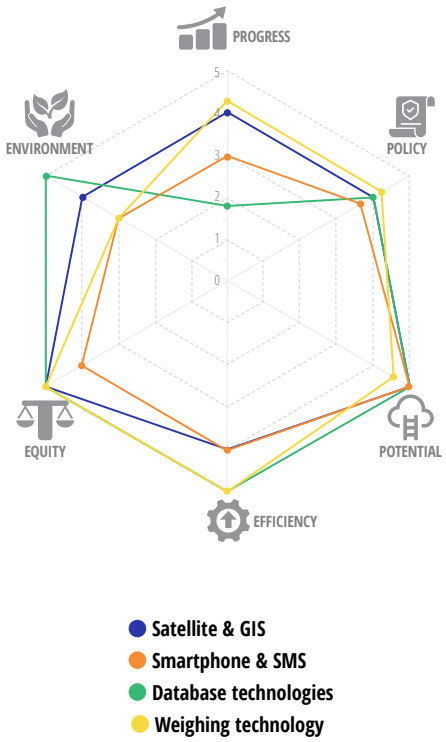
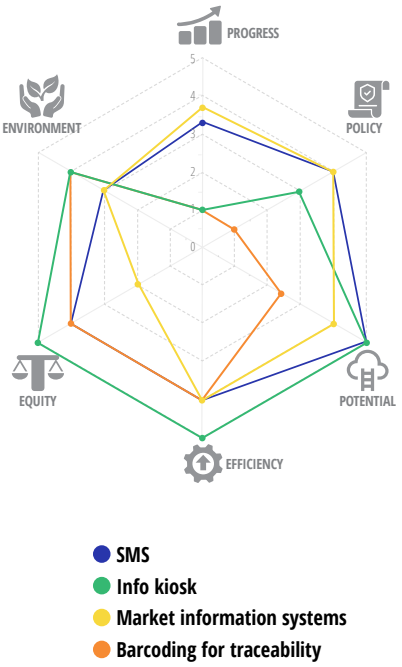
There is great need for agricultural intensification in Rwanda. The private sector's agility, streamlined resources allocation, and responsiveness to market demand positions it well to pursue digital solutions in concert with government institutions, which can provide funding and capacity building. Rwanda is highly rated in terms of ease of doing business, and it has an environment open for international companies to import new ideas and technologies. Private institutions like the Bank of Kigali, Klab, and N-Frnds are already working in this space via public-private partnerships. The primary bottleneck to building such additional alliances is the unsustainability of current business models. Overcoming this issue will attract local and international business expansion at all scales in Rwanda.

Finance options

The success of Rwanda's digital agriculture transformation will depend heavily on the financing available from public, private, and international donor sources. Meeting the national commitment to the 10% CAADP Malabo Declaration would be a clear step in the right direction. Guided by an enabling policy environment, such governmental investment may unlock vital private investments. Ongoing, coordinated engagement with NGOs and the private sector will also be necessary to remain aligned on priorities, allocations of funds, and sustainability practices.

Table 1: Prioritized technologies

	Challenge	Technology	Outcome	Analysis
INPUT HUB	Lack of risk mitigation strategies	**Smartphone app for decision support (high-tech)**	Improved access to financial and risk mitigation/insurance services for actors across the value chain	
		Unstructured Supplementary Service Data (USSD) for decision support (low-tech)		
	Lack of awareness and uptake of available technology solutions	**Short Message Service (SMS) for advisory services and decision support**	Provide advisory services and dissemination of information on new or improved technologies	
		Interactive Voice Response (IVR) for advisory services and decision support		
PRODUCER HUB	Lack of data to support farm management	**Digital farm registration for a farmland database**	Improved farm management and supported crop insurance systems	
		Digitized farm records for improved farm management		
		Remote sensing & Global Positioning System (GPS) developing geotagged records for crop monitoring, insurance and farm management		
	Low mechanization, manual labor drudgery	**Satellites and drones for enhanced remote sensing and land/crop monitoring**	Mechanization of farming systems for improved productivity, resource use efficiency and sustainable intensification	
		Internet of Things (IoT) for smart farming		
	No traceability	**Barcoding for tracability**	Enhanced traceability of source and supply chain of agricultural products	
	Limited market access and information	**E-commerce for market information**	Linking farmers to markets, reducing the number of middlemen	
	Poor access to finance services	**E-wallet and mobile money**	Enhanced creditworthiness and access to finance for farmers	

	Challenge	Technology	Outcome	Analysis
DISTRIBUTION HUB	Poor road quality	**Satellite and Geographic Information System (GIS) for weather forecasting and road mapping**	Improved road access to farm communities given seasonal challenges	
	limited direct links from markets directly to farming communities and producers	**Smartphone apps and Short Message Service (SMS) for online stores and e-markets**	Linking farmers to markets, reducing the number of middlemen	
	Poor postharvest facilities	**Database technologies for digitized records of stored produce and owners**	Providing storage and holding/warehousing facilities to reduce postharvest losses and retain product quality	
		Weighing technologies	Farmers are able to aggregate and sell their production to retailers	
CONSUMER HUB	Lack of nutrition information	**Short Message Service (SMS) / Interactive Voice Reponse (IVR) for nutritional information for low-tech consumers**	Providing nutritional advisory information to consumers	
	Social barriers (tradition, culture, mindset)	**Digital information desk regarding new products**	Increased consumer awareness and demand for niche products	
	Feedback platforms	**Market information systems**	Soliciting and managing feedback from consumers of agricultural products	
	Traceability of source, channel of distribution, and status of agricultural products	**Barcoding and geo-tagging for tracibility**	Improved traceability of agricultural products	

Outlook / synthesis of recommendations

Rwanda has made extraordinary digital technology progress over the last decade. Connectivity is improving, subscriptions rates have tripled, and costs are falling even as the country extends coverage to nearly all of its land area. Digital agriculture solutions are being developed, piloted, and accepted by stakeholders across all four hubs. This indicates significant potential for digital solutions that address some of the key remaining gaps in the Rwandan agricultural sector, including decision support and agro-advisory services, access to financial services, mechanization, risk management mechanisms, supply chain traceability, and postharvest facilities. Digital agriculture has robust support from the government of Rwanda. However, potential barriers to the mainstreaming of digital agricultural solutions still exist across all hubs, including the high cost of equipment and technologies, a domestic skills gap, and low digital literacy.

Our research suggests that a combination of low-tech and high-tech digital solutions offers the greatest promise for tackling challenges and facilitating adoption. Stakeholders who focus their solutions using SMS/IVR systems, database technologies, remote sensing, GPS, market information systems, GIS technologies for forecasting, and USSD platforms are most likely to bring scalable and high-impact solutions to the agriculture sector in Rwanda.

The continued support of national policies, an expanded agricultural research and extension system, and partnerships that leverage the complementary strengths of public, private, and international development will also be crucial to the success of digital agricultural innovations in Rwanda.

References

Adewopo, Julius. "Citizen Science and ICT for Advancing the Prevention and Control of Banana Xanthomonas Wilt (BXW) in East and Central Africa." IITA (blog), 2018. http://www.iita.org/iita-project/citizen-science-and-ict-for-advancing-the-prevention-and-control-of-banana-xanthomonas-wilt-bxw-in-east-and-central-africa-2/.

Africa, CNBC. "Is Rwanda Ready for 5G?," May 14, 2018. https://www.cnbcafrica.com/article/2018/05/14/is-rwanda-ready-for-5g-2/.

Andela. "Apply To The Fellowship," 2019. https://andela.com/fellowship/apply/.

Bimenyimana, Samuel, Godwin N. O. Asemota, and Lingling Li. "The State of the Power Sector in Rwanda: A Progressive Sector With Ambitious Targets." Frontiers in Energy Research 6 (2018). https://doi.org/10.3389/fenrg.2018.00068.

Data Bank. "Rwanda." Country Profile. World Bank, 2018. https://databank.worldbank.org/views/reports/reportwidget.aspx-?Report_Name=CountryProfile&Id=b450fd57&tbar=y&dd=y&inf=n&zm=n&country=RWA

Editor RBD. "Rwanda Eyes 5G Internet by End of 2019." Rwanda Business Daily (blog), October 5, 2018. https://rwandabusinessdaily.com/rwanda-eyes-5g-internet-by-end-of-2019/.

e-Government Knowledge Base. "Country Information: Rwanda." United Nations, 2018. https://publicadministration.un.org/egovkb/en-us/Data/Country-Information/id/142-Rwanda.

FAO. "Country Programming Framework for Rwanda," 2013. http://www.fao.org/3/a-bp633e.pdf.

"Rwanda at a Glance," 2019. http://www.fao.org/rwanda/fao-in-rwanda/rwanda-at-a-glance/en/.

Global Information Technology Report. "Rwanda." Network Readiness Index. Economy Profiles. WeForum, 2016. http://www3.weforum.org/docs/GITR2016/WEF_GITR_Rwanda_2016.pdf.

GSMA Intelligence. "Data by Country," 2019. https://www.gsmaintelligence.com/data/.

Human Development Reports. "Rwanda." United National Development Programme, 2017. http://www.hdr.undp.org/en/countries/profiles/RWA.

In-country Expert Workshop Representative. BK TecHouse, August 2019.

Institute of Policy Analysis and Research. "Annual Analysis of Rwanda's Agriculture Budget Expenditure 2015-2016." ActionAid, October 2015. http://www.ipar-rwanda.org/IMG/pdf/annual_analysis_of_rwanda_s_agriculture_budget_expenditure_2015-2016.pdf.

International Telecommunications Union. "Executive Summary: Rwanda." ICT centric innovation ecosystem country review. Geneva, Switzerland, 2017. https://www.itu.int/en/ITU-D/Innovation/Documents/Publications/Executive_Summary-Brochure_Rwanda_409090.pdf.

kLab. "Open Space for IT Entrepreneurs," 2012. https://klab.rw/public/about.

Ministry of ICT and Innovation. "Rwanda's Digital Transformation." presented at the 5 th eGovernance Conference, May 2019. https://2019.egovconference.ee/wp-content/uploads/sites/2/2019/02/Paula-Ingabire-Rwandas-Digital-Transformation.pdf.

National Institute of Statistics Rwanda. "Agricultural Household Survey," 2017. http://www.statistics.gov.rw/publication/agricultural-household-survey-2017.

"GDP National Accounts (First Quarter 2019)," 2019. http://www.statistics.gov.rw/publication/gdp-national-accounts-first-quarter-2019.

N-Frnds. "Agriculture." Accessed October 9, 2019. https://www.nfrnds.com/agriculture/.

Power Africa. "Rwanda." USAID, November 14, 2018. https://www.usaid.gov/powerafrica/rwanda.

PwC. "Sustaining the Momentum: Rwanda's 2019/20 National Budget Bulletin," June 2019. https://www.pwc.com/rw/en/pdf/rwanda-budget-analysis-2019-20.pdf.

Republic of Rwanda. "National ICT4 Ag Strategy (2016 -2020)." Scribd, 2016. https://www.scribd.com/document/324213359/ICT-for-Agriculture-policy-and-Strategic-Plan-2016-2020-Rwanda.

RIA. "After Access Household and Individual ICT Survey," 2017.

Rwanda Agriculture Board. "Rwanda Agriculture and Animal Resources Development Board," 2019. http://www.rab.gov.rw/index.php?id=180.

"Rwanda Economic Update." Rwanda at Work. The World Bank, February 2016. http://documents.worldbank.org/curated/en/126991468197359041/pdf/103618-WP-P156677-PUBLIC-Rwanda-Economic-Update-Feb-25-2016.pdf.

Rwanda Utilities Regulatory Authority. "Statistics Report for Telecome, Media, and Postal Sector as of the First Quarter of the Year 2019," 2019. https://rura.rw/fileadmin/Documents/ICT/statistics/Quarterly_Telecom_Statistics_report_as_of_March_2019_.pdf.

Systems Lead. One Acre Fund, September 2019.

The World Bank. "Access to Electricity (% of Population)." Data, 2017. https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS.

"Agricultural Development in Rwanda." Projects and Operations, January 23, 2013. https://projects.worldbank.org/en/results/2013/01/23/agricultural-development-in-rwanda.

"Arable Land (% of Land Area) - Rwanda." Data, 2018. https://data.worldbank.org/indicator/AG.LND.ARBL.ZS?locations=RW.

"Population Density (People per Sq. Km of Land Area) - Rwanda." Data, 2018. https://data.worldbank.org/indicator/EN.POP.DNST?locations=RW.

"Population, Total - Rwanda." Data, 2018. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=RW&view=chart.

Tsan, Michael, Swetha Totapally, Michael Mailu, and Benjamin Addom. "The Digitalisation of African Agriculture Report." CTA, 2019. https://www.cta.int/en/digitalisation-agriculture-africa.

UNDP. "Gender Development Index," 2017. http://hdr.undp.org/en/composite/GDI.

World Bank. "Future Drivers of Growth in Rwanda: Innovation, Integration, Agglomeration, and Competition." Government of Rwanda, 2019. http://documents.worldbank.org/curated/en/680671541618477651/pdf/131875-V2-WP-PUBLIC-Disclosed-11-9-2018.pdf.

"Population Growth (Annual %) - Sub-Saharan Africa." Data, 2018. https://data.worldbank.org/indicator/SP.POP.GROW?locations=ZG&most_recent_value_desc=true&view=chart.

"Poverty Headcount Ratio at $1.90 a Day (2011 PPP) (% of Population) - Rwanda." Data, 2016. https://data.worldbank.org/indicator/SI.POV.DDAY?locations=RW&view=chart.

Annex

Digital infrastructure and technologies definitions and examples

Technology	Description	Applications	Examples
Mobile Phones & Broadband Internet	Infrastructure, hardware, and software system that enables a portable device, usually a mobile phone, to send and receive messages, make and receive calls, and (in some cases) access the Internet. Smartphones have touch-screens, while feature phones do not. Broadband Internet infrastructure is always on, and that delivers a minimum of 5 megabits per second (mbps) to homes and businesses	• Information, knowledge sharing, and advisories on weather, extension, early warnings, pricing, market supply and demand • Financial services such as credit, loan, payment, vouchers. • Digital receipts, records, contracts • Market linkages e.g. input access, real-time communications between stakeholder hubs, equipment rentals, product monitoring and tracing	• One Acre Fund • AgriProFocus Rwanda • IKOFI - Bank of Kigali • Smart Nkunganire System (SNS) • Mkulima Young • MAHWI TECH • AMITSA • Metajua • SPIDERBIT • Virtual City
Big data, data analytics, data management	High-speed collection and processing of large quantities of interconnected (structured or unstructured) datasets from multiple sources and their presentation in a single interface to a user	• Weather forecasting • Crop forecasting • Supply and demand prediction • Precision agriculture • Product traceability, quality control • Financial services • Data and information sharing • Digital records • Information for extesion services • Early warning systems	• N-Frnds • Metajua • ACRE • Farmforce • SCOPEinsight • SarVision
Artificial intelligence / machine learning	Computer systems able to perform tasks that normally require human intelligence, such as speech recognition, decision-making, and translation	• Precision farming • Market information • Financial services e.g. determining credit scores • Extension services • Data and information sharing • Digital recordkeeping • Early warning systems	• SOWIT (R&D phase) • BXW Application - IITA
Internet of Things	Assembly of sensors, networks, and analytics communicating on the same platform and/or using the same protocols	• Extension • Farm and soil evaluation • Smart greenhouses • Financial services • Data and information sharing • Digital recordkeeping • Early warning systems • Irrigation systems	• No local solutions available
Blockchain	An open, distributed ledger to record transactions between two parties efficiently and in a verifiable and permanent way	• Product and supply monitoring and tracing • Quality control • Digital contracts and recordkeeping • Financial services e.g. credit, loans, advances on receivables, insurance	• No local solutions available
Drones	Small remote-controlled aircrafts with no human pilot onboard	• Farm health evaluations • Tailored extension services	• Charis Unmanned Aerial Solutions
Weather stations	Permanently installed devices that detect weather metrics, e.g. precipitation, temperature, wind speed, humidity, and pressure	• Weather forecasting • Early warning systems	• ACRE • Rwanda Meteorology Agency
Geographic Information Systems	Systems designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data	• Extension and advisories • Early warning systems • Financial products • Information sharing • Precision agriculture • Farm monitoring and evaluation	• PULA • SarVision

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