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Digital Agriculture Profile • Kenya

HIGHLIGHTS

Kenyan agriculture is very high risk, making input markets, product quality and quantity, and distribution networks extremely unstructured and volatile

The current set of technologies available to the Kenyan agricultural sector is broad, but has not yet crossed into mainstream use. **About 113 institutions offer digital solutions for agriculture in Kenya,** 64 of which are headquartered there

High technology costs, low digital literacy, limited infrastructure access, and a weak enabling policy environment are the primary constraints to adoption of digital agricultural solutions

Mobile, data, blockchain, and weather station technologies are the most promising high-impact solutions for the challenges facing Kenyan agricultural stakeholders

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

21% OF RURAL KENYANS HAVE **ELECTRICITY SERVICES**

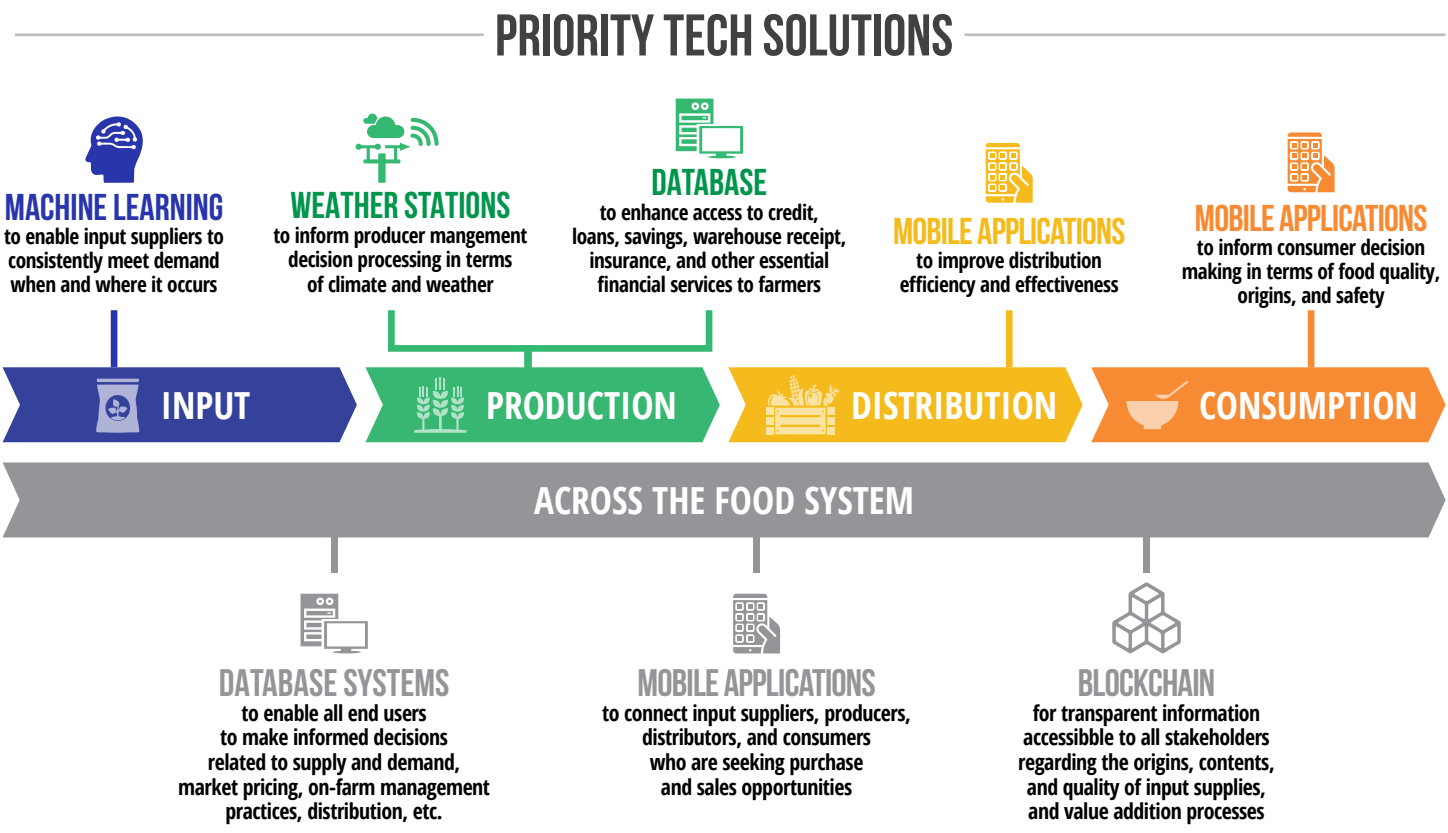
49% OF **PEOPLE AGES 18-35** OWN A SMARTPHONE

MEN ARE **20%** MORE LIKELY TO OWN **A SMARTPHONE THAN WOMEN**

BETWEEN 2013-2018 INTERNET/DATA SUBSCRIPTIONS HAVE INCREASED BY **268%** TO **OVER 45 MILLION**

MOBILE SUBSCRIPTIONS HAVE INCREASED BY **63%** **TO 49.5 MILLION** IN THAT SAME TIME PERIOD

17% OF KENYA'S LANDMASS HAS **FIBER OPTIC COVERAGE**



Introduction

The Kenyan agricultural sector is its economic cornerstone. Agriculture employs more than 40% of the total population and contributes 30% to the Gross Domestic Product (GDP).[1] Recent years have brought significant new challenges, and important investment opportunities to Kenya's agriculture.

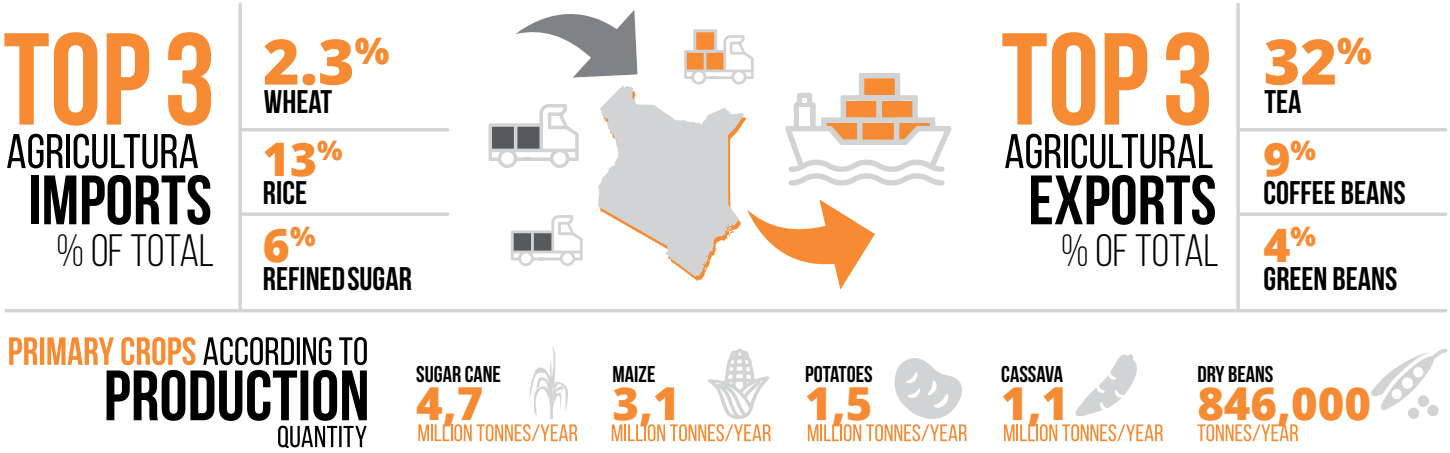
Kenya's agricultural producers currently lack the contemporary technologies and decision- support tools necessary for sustaining and improving yields. This challenge is exacerbated by climate change, which has forced farmers to grapple with increasingly volatile weather, more frequent extreme weather events, and accelerated environmental degradation. Other stakeholders along agricultural value chains, including input providers, distributors, and consumers, also face substantial challenges. Some of these include product quality, monitoring, traceability, pricing, cold-chain and storage, value-addition, automation, and communication.

One possible solution to addressing these challenges is digital agriculture. While the concept of digital agriculture is relatively new and still evolving, foundational technologies, such as mobile and Internet connectivity, are already available to support innovative digital solutions to many major challenges facing the agricultural sector.

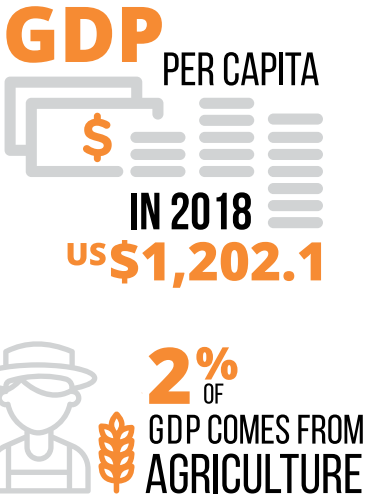
Digital agriculture is the use of new and advanced technologies, integrated into one system, to enable farmers and other stakeholders to improve their products and processes. Integrating digital solutions into agriculture can improve efficiency by decreasing financial and labor costs, providing information to support management decisions, increasing product quantity and/or quality, reducing losses, and/or 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 major constraints within the agricultural sector.

As part of the initiative on "What's Cooking: Digital Transformation of the AgriFood System" led by The World Bank, this Digital Agriculture Profile for Kenya leverages the expertise of stakeholders to evaluate the current

1 Kenyan Ministry of Agriculture, Livestock, Fisheries and Irrigation, "Agricultural Sector Transformation and Growth Strategy."



landscape of digital agriculture in Kenya, 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 Kenya can begin in earnest.



National Context

Economic relevance of agriculture

Agriculture plays a vital role in the economy of Kenya, accounting for a third of national GDP[2] and employing over 8.6 million farmers. The majority of these are subsistence farmers, meaning they rely on agriculture as both their primary source of food and of income. The national agricultural GDP growth rate has been in decline, from 10% in 2010 to only 2% in 2017.[3] Despite agriculture's huge contribution to the national economy, less than 5% of the national budget goes to the agricultural sector. Of this, 2.3% is devoted to financing agricultural subsidies.

Leading agricultural exports in Kenya include tea (32% of all exports), coffee beans (9%), green beans (4%), avocado (2%), and nuts (2%). Major agricultural imports include wheat (16%), rice (13%), refined sugar (6%), maize (4%), and raw tobacco (3%).[4]

Agricultural production systems

Kenya is divided into seven agro-ecological zones based on precipitation and soil type: Western Zone, Rift Valley, Central Highlands, Semi-Arid Uplands, Coast, Central Arid and Semi-Arid Lands, and Northern Arid and Semi-Arid Lands. These agro-ecological zones vary in terms of number of farmers, number of growing seasons, and primary crop types. The Western Zone and the Central Highlands receive the majority of precipitation and are the most densely populated.[5]

In 2017, Kenya produced 4,751,609 tonnes of sugar cane, 3,186,000 tonnes of maize, 1,519,870 tonnes of potato, 1,112,000 tonnes of cassava, and 846,000 tonnes of beans. As the country's primary staple crop and a major source of income for smallholders, maize dominates 34% of the agricultural landscape. Beans cover 18%. Cut flowers, sugarcane, vegetables, and coffee together account for an

2 Gross Domestic Product.

3 World Bank, "World Development Indicators."

4 Food and Agriculture Organization of the United Nations, "FAOSTAT"; World Bank, "World Development Indicators."

5 Kenyan Ministry of Agriculture, Livestock, Fisheries and Irrigation, "Agricultural Sector Transformation and Growth Strategy."

additional 20%. Cowpea and pea cover 6% of agricultural land. Tea occupies just 4% of all productive land, and constitutes more than 70% of all cash crop market value.

Kenya has the second largest livestock herd in Africa, and ranks 13th in the world in terms of dairy cows. Despite this, the country is 138th in the world in terms of yields. Dairy production is concentrated in the high-precipitation Central Highlands and Western Zone, and more than 60% of beef cattle are produced in the arid and semi-arid areas

People, livelihoods and agriculture

About 36% of Kenyans live below the poverty line, and the annual population growth rate is 2.7%. Most impoverished people are rural smallholder farmers. Smallholders (<12 acres) comprise 66% of all Kenyan farms. Rural communities currently constitute 73% of the population. There is significant migration toward urban areas. The urban expansion rates of 4.4% far outpaces national population growth.[6]

Kenya ranks 142 in the world on the Human Development Index, and 137 on the Gender Inequality Index.[7] About 7.4% of Kenyans are unemployed,[8] of which 85% are under 35 years of age. More than 30% of households in Kenya are unable to buy sufficient food, and food price volatility in Kenya is double that of the entire East African Community.[9]

Literacy rates in Kenya are estimated at 78%.[10] Approximately 47% of rural Kenyans have access to improved water sources, and 21% have electricity.[11] A strong reliance on cereals for caloric intake has contributed to high malnutrition levels in the country; 11% of children under five years are stunted.[12]

ABOUT 36% OF KENYANS LIVE BELOW THE POVERTY LINE, AND THE ANNUAL POPULATION GROWTH RATE IS 2.7%

MOST IMPOVERISHED PEOPLE ARE RURAL SMALLHOLDER FARMERS

SMALLHOLDERS (<12 ACRES) COMPRISE 66% OF ALL KENYAN FARMS

RURAL COMMUNITIES CURRENTLY CONSTITUTE 73% OF THE POPULATION

KENYA RANKS 142 IN THE WORLD ON THE HUMAN DEVELOPMENT INDEX, AND 137 ON THE GENDER INEQUALITY INDEX

ABOUT 7.4% OF KENYANS ARE UNEMPLOYED, OF WHICH 85% ARE UNDER 35 YEARS OF AGE

LITERACY RATES IN KENYA ARE ESTIMATED AT 78%

APPROXIMATELY 47% OF RURAL KENYANS HAVE ACCESS TO IMPROVED WATER SOURCES

21% HAVE ACCESS TO ELECTRICITY

11% OF CHILDREN UNDER FIVE YEARS ARE STUNTED

ACCESS TO ELECTRICITY

6 United Nations, "Kenya."

7 United Nations Development Programme, "Gender Inequality Index."

8 Kenya National Bureau of Statistics, "Basic Report on Well-Being in Kenya."

9 Kenyan Ministry of Agriculture, Livestock, Fisheries and Irrigation, "Agricultural Sector Transformation and Growth Strategy."

10 Index Mundi, "Kenya Literacy - Demographics."

11 World Bank, "World Development Indicators."

12 Kenya National Bureau of Statistics, "Kenya Demographic and Health Survey."

Challenges in the agricultural sector[13]

Kenyan farmers generally lack the modern technologies necessary to increase and sustain yields. The country has low mechanization rates relative to other Sub-Saharan African nations. Rural smallholders' are extremely financially constrained; most must make daily decisions between competing priorities such as food purchases, school fees, and buying farm inputs such as labor and fertilizer. This is exacerbated by a lack reasonable access to basic financial services, such as credit, loans, warehouse vouchers, cooperative bulk purchasing and sales, and savings accounts. Information services to support decision making are also largely absent; the majority of Kenyan farmers must make farm management decisions without knowing the weather forecast, market demand and prices, soil characteristics, pest incidences in the area, and other crucial information.

Only 7% of Kenyan agricultural land is irrigated, making the sector heavily dependent on rainfall. Increased climate volatility as an effect of climate change has thus substantially increased the risks associated with farming. Kenyan farmers are grappling with increasingly unreliable rainfall, long dry spells, frost, high temperatures, and frequent floods. Such climate incidences aggravate existing environmental degradation issues, in particular low soil fertility and erosion.

High quality inputs would, in many cases, substantially improve smallholders' yields, profits, and climate resilience. However, access to high quality inputs can prove quite challenging for Kenyan farmers. Poor road networks make accessing input markets a time-intensive challenge. Products such as pesticides and fertilizers are frequently altered, and a lack of monitoring systems and traceability prevents quality control and assurance. In combination with the aforementioned financial constraints and climactic volatility, these issues make inputs an investment that often does not warrant the risk. Low demand aggravates accessibility issues by instigating sporadic supply. As such, Kenya's input usage rates remain low; fertilizer application sits at an average of 33.6 kg/ha, well below the Abuja Fertilizer Declaration[14] goal of 50 kg/ha.

Kenya's agricultural markets are highly unstructured, resulting in significant price volatility, high transaction costs, small gross margins, and generally poor market access. Postharvest storage and value-addition processing facilities are inaccessible to most. This, in combination with poor road networks, results in high postharvest losses and decreased product quality. Additionally, as most products cannot be stored or processed, farmers are limited to selling during harvest, when there is an oversupply and prices are at their lowest. Subsequently, there is an over-demand period in which imported goods are sold at premium prices. Food insecurity in some areas of Kenya is primarily due to poor distribution from areas of high production (Western Zone, Central Highlands) to areas of low production (Coastal, Northern).

Kenyan agricultural policy is well-established, but in some cases has proven counter-effective or poorly enforced. Pro-import trade policies create significant competition for local markets. Mismanagement of government agricultural parastatals results in delays in paying farmers, poor distribution of produce, and lack of storage facilities, among other issues. Poor enforcement of environmental policies has resulted in significant encroachment of forests and wetlands; consequent environmental degradation exacerbates farmers' struggle with climatic volatility. Weak enforcement strategies for existing land policies create significant land tenure insecurity. This is a major contributor to low productivity; long-term investment in land quality is not an effective strategy for farmers who have no tenure to the land.

Despite its significant economic contributions, Kenyan agriculture has yet to attain the 10% budgetary allocation put forth in the Malabo Declaration.[15] This deprives the government of sufficient capacity to render services crucial for developing the sector, adapting to a changing climate, and building resilience and productivity among small-scale farmers.

Current landscape of digital tools and policies

Digital infrastructure, availability and access

The current set of technologies available to the Kenyan agricultural sector is broad (Table 2), but has not yet crossed into mainstream use. Both geographic and demographic limitations exist. The majority of rural areas do not yet have mobile or Internet coverage. A significantly higher percentage of men (43%) own Internet-enabled smartphones compared to women (34%). More youth ages 18-35 own Internet-enabled smartphones compared

13 Climate Change, Agriculture and Food Security, "Kenya County Climate Risk Profiles."

14 New Partnership for Africa's Development Planning and Coordination Agency, "The Abuja Declaration on Fertilizers for an African Green Revolution."

15 Sidler, "Overview on the CAADP, the 2003 Maputo and Particularly 2014 Malabo Declarations."

to any other age group (49%), suggesting a greater digital literacy barrier for older individuals.[16]

The ICT[17] Development Index shows Kenya improving from year to year, but not quickly enough to keep pace with other countries.[18] As such, it remains in the lower 30% of countries worldwide, and well below the international average. The Telecommunication Infrastructure Index shows that Kenyan digital infrastructure improved substantially through 2016, but has had relatively little continued development since then. Kenya's 2018 Telecommunication Infrastructure Index score is 0.1901; this is well below the world average (0.4155) and the regional leader (Mauritius, 0.5435) and barely better than Kenya's 2016 score of 0.1801.[19] The Global Connectivity Index 2018 scores Kenya at 29/100, noting that both mobile broadband and bandwidth affordability have improved over the past year.

About 25% of all Kenyans access the Internet, and another approximately 25% use wireless connectivity.[20] And estimated 98% of Kenyans own some type of mobile phone, and over 80% have mobile subscriptions. From 2013 through the end of 2018, Internet/data subscriptions in Kenya increased 268%, and now stand at more than 45 million . Over the same time period, mobile subscriptions increased 63% to 49.5 million. There are also currently 31.6 million active mobile money subscriptions. Some 30% of Kenya's approximately 50 million residents own multiple subscriptions; this is often to improve coverage and/or access lower rates. Safaricom, which hosts the revolutionary m-Pesa, now holds 63% of all mobile subscriptions; a 6-percent increase from previous year.[21]

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16 Ministry of Public Service, Youth and Gender Affairs and State Department for Public Service and Youth, "Kenya Youth Development Policy"; Eliot, "Data Report on Farming in Kenya and Mobile Phone Usage."

17 Information Communication Technology.

18 ITU, "Global ICT Development Index."

19 United Nations, "Kenya E-Government Development Index."

20 Huawei, "Global Connectivity Index 2018."

21 United Nations, "Kenya E-Government Development Index."

22 An Africanist Perspective, "Mobile Connectivity in Kenya Is at 97.8%."

23 Communications Authority of Kenya, "Annual Report for the Financial Year 2016-2017"; Communications Authority of Kenya, "Annual Report for the Financial Year 2013-2014."

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MORE YOUTH AGES 18-35 OWN INTERNET-ENABLED SMARTPHONES THAN ANY OTHER AGE GROUP (49%) SUGGESTING A GREATER DIGITAL LITERACY BARRIER FOR OLDER INDIVIDUALS

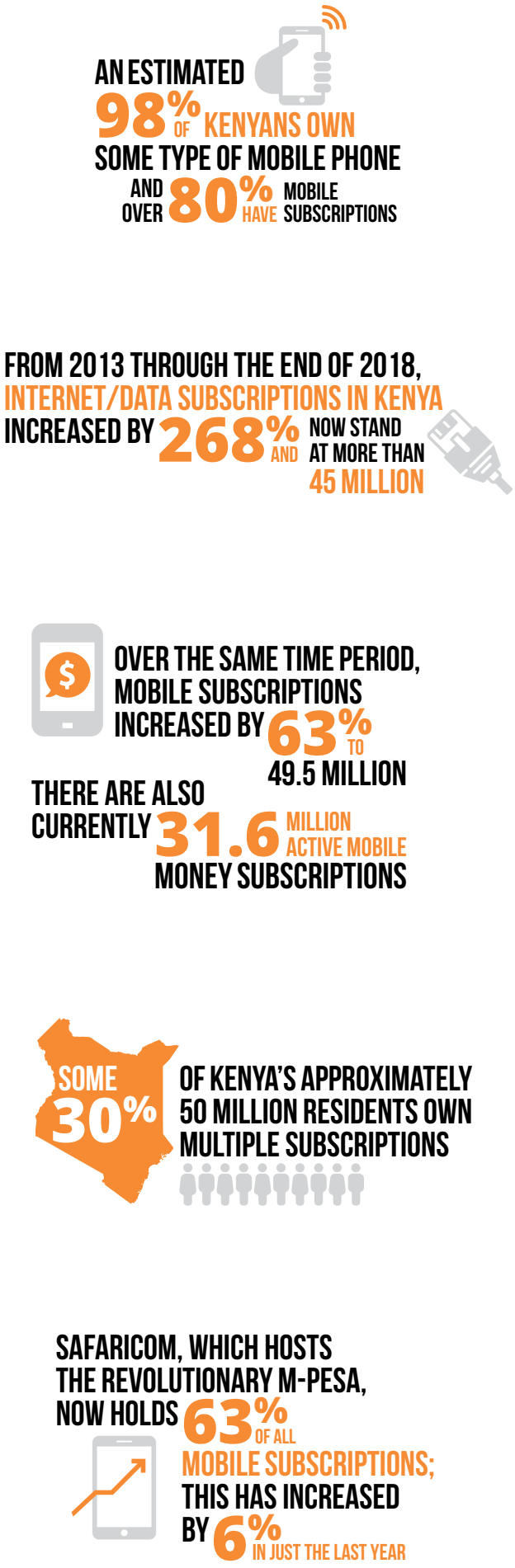
THE ICT DEVELOPMENT INDEX SHOWS KENYA REMAINS IN THE LOWER 30% OF COUNTRIES WORLDWIDE, AND WELL BELOW THE INTERNATIONAL AVERAGE

KENYA'S 2018 TELECOMMUNICATION INFRASTRUCTURE INDEX SCORE IS 0.19 THIS IS WELL BELOW THE WORLD AVERAGE (0.41) AND THE REGIONAL LEADER (MAURITIUS, 0.54) AND BARELY BETTER THAN KENYA'S 2016

THE GLOBAL CONNECTIVITY INDEX 2018 SCORES KENYA AT 29/100

25% OF KENYANS HOUSEHOLDS HAVE INTERNET ACCESS

AND ANOTHER APPROXIMATELY 25% USE WIRELESS CONNECTIVITY



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Internet speeds are also reaching new heights. The Communications Authority of Kenya reports a 286% increase in the number of 3G subscribers (now at nearly 43,000) and a 107% increase in 2G subscribers (now at nearly 138,000) fbetween 2013 and 2018. 4G has also come online in that time, and now has nearly 4,000 subscribers.[25] Nevertheless, access continues to vary significantly across Kenya's geographic regions. 2G/3G/4G coverage is concentrated in urban areas. Many rural residents are more than 2km away from the nearest mobile coverage area.[26] Even in areas where Internet is available, it is not yet affordable for many communities; 1GB of mobile broadband data costs over 4% of GNI,[27] or about US$65.[28] This would be the equivalent of paying US$2,100 for 1 GB of mobile broadband in the USA. A similar situation is seen for optic fiber broadband services; most 83% of the Kenyan is uncovered, and less than 1% of Kenyans use broadband.[29]

End-user diversity and demand

Digital agriculture end users can be 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 within multiple end user hubs.

The **Input hub** includes all actors providing agricultural inputs, such as seeds, feeds, agrochemicals, machinery, and finance. Primary challenges faced by this hub include minimal decision support tools, poor market linkages, inconsistent demand and supply, and a lack of financial services.

The **Production hub** fundamentally consist of farmers and livestock keepers. Producers grapple with a lack of decision support tools and knowledge sharing, little

24 Communications Authority of Kenya, "Statistics."

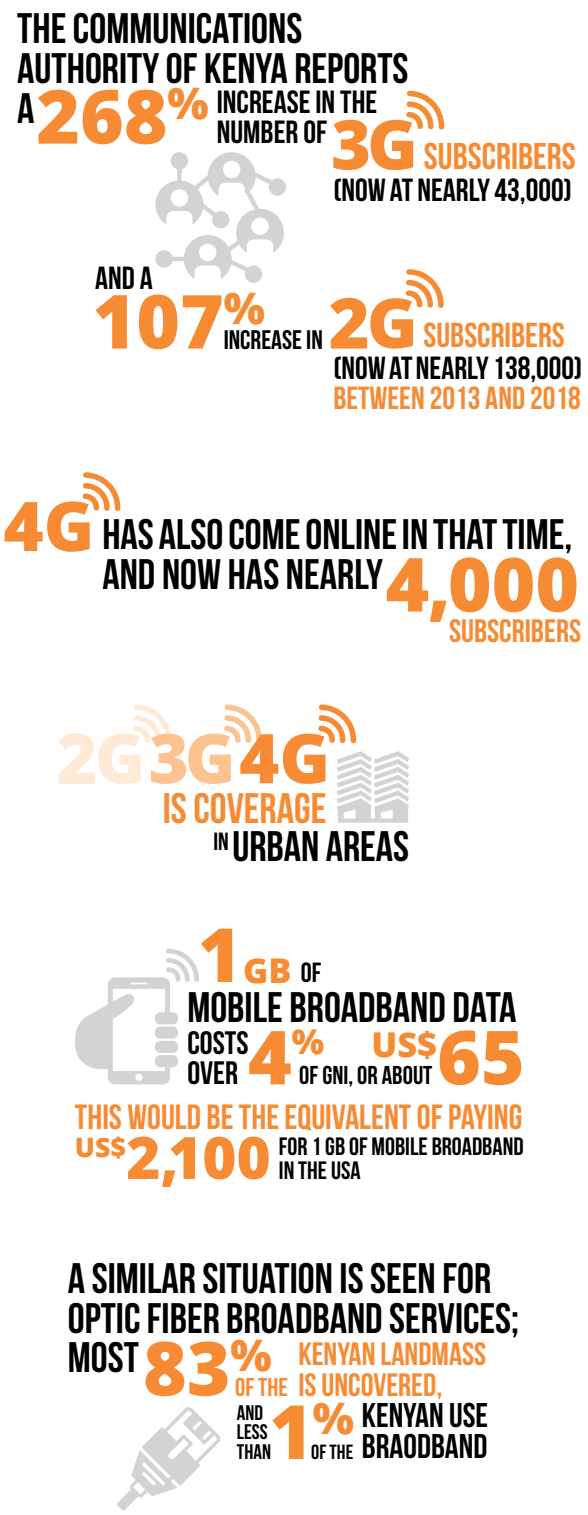
25 Communications Authority of Kenya, "Annual Report for the Financial Year 2013-2014"; Communications Authority of Kenya, "Annual Report for the Financial Year 2016-2017."

26 NPERF, "2G /3G /4G Safaricom Coverage Map."

27 Gross National Income.

28 Alliance for Affordable Internet, "Affordability Index."

29 United Nations, "Kenya E-Government Development Index."



access to financial services, poor market linkages, low mechanization, and a lack of input traceability.

The **Distribution hub** consists of all actors in the value chain between the farmer and the consumer; this includes traders, transporters, and processors, among others. Significant barriers for this hub include poor market linkages, low transparency, a lack of real-time communications, and poor monitoring and traceability systems.

The **Consumer hub** consists of consumers of both raw and processed agricultural—in effect, the entire population. Primary barriers faced by this hub include poor market linkages, insufficient monitoring and traceability systems, and a lack of purchase decision support tools.

Smart-device[30] ownership remains limited across all four hubs, and is expected to increase significantly by 2024. An estimated 90% of the Input, Production and Distribution hubs, and 60% of the Consumer hub, currently have feature phone access. Connectivity is expected to improve along with technology access; current 2G/3G connections are likely to be replaced by 4G/5G mobile connections for all hubs over the next 5 years. These faster network connections will facilitate expanded use of more advanced technologies, such as IoT[31] and big data, particularly for the Input and Production hubs.

At least some individuals within each hub currently have access to mobile- and Internet-based input, price, weather, pest, and market information services; the degree of access is expected to increase concomitantly with expanded infrastructure coverage in the coming years. The Input and Distribution hubs already employ advanced technologies, such as blockchain, supply monitoring, and drones, to some extent; isolated usage of such systems will likely emerge in the Production hub by 2024.

Institutions and policies for Digital Agriculture

Various institutions, including corporations, donor institutions, government agencies, and small start-ups, offer an array of digital agricultural solutions in Kenya (Table 2). About 113 institutions offering digital agriculture providers have a presence in Kenya, 64 of which are headquartered in the country.[32]

International donors, including The World Bank, CGIAR,[33] USAID,[34] the African Development Bank, and the Gates Foundation, are major sources of finance for Kenyan digital agriculture. Network operators such as Safaricom and Telkom offer general services, including connectivity and mobile money, that are readily applied to the agricultural sector. Other private actors, such as Upande Limited and Twiga, offer agriculture-specific, in-field digital solutions.

30 Smart devices are characterized by a touchscreen. For example, smartphones have a touchscreen and feature phones do not.

31 Internet of Things.

32 Center for Agriculture and Rural Cooperation, "Digitalization for Agriculture Report - Africa."

33 Consultative Group for International Agricultural Research.

34 United States Agency for International Development.

The Kenyan government's federal strategies play an important role in creating a strong foundation for digital agriculture. As part of Vision 2030, the Kenyan government has articulated its development foci—housing, universal healthcare, manufacturing, and food security--in The Big Four Agenda. Innovation in the agricultural sector directly addresses two of these pillars.

Multiple government policies emphasize the need for a digital transformation of the economy, highlighting digital capacity development and increasing broadband connectivity, particularly in rural areas. However, despite the emphasis on digital solutions in other sectors, federal policy references to digital agriculture remain very limited, and a national policy for digital agriculture solutions has not been put forth.

Recent federal policies addressing digital technologies in general include the National Information and Communication Technology Policy (2006, amended 2016), the National ICT[35] Masterplan (2014-2018), the Policy on Remotely Piloted Aircraft Systems (2017), the National Broadband Strategy (2018), and the Kenya Digital Economy Blueprint (2019).

National policy does little in terms of promoting the establishment of mobile infrastructure. Database management, enjoys somewhat stronger policy support under the National Broadband Strategy. Most notably, the National Broadband Strategy emphasizes increasing national 3G coverage to 94% with a focus on rural areas, and increasing the number of digitally literate government workers by 50% by 2023. Digital agriculture, particularly IoT[36] and technologies for efficient supply chain management, are identified as strong enablers for achieving the food security pillar of the Big Four Agenda.

The National ICT[37] MasterPlan identified the Kenyan government as its primary funder by way of the Universal Access Fund, the Equalization Fund (for marginalized communities), and the National Research Fund. There is limited information available as to what quantity of funds came from these sources to facilitate the plan's 2014-2018 implementation.

35 Information Communication Technology.

36 Internet of Things.

37 Information Communication Technology.

Digital agricultural services and applications available

Many organizations in Kenya currently offer digital credit, inputs, information sharing, and market linkage services for agriculture stakeholders (Figure 1). Farm data collection, postharvest technology, soils analysis, and resource use services are also available.

The private sector plays a key role in leading digital innovation and profitable digital solutions in Kenya. Safaricom, which now holds 63% of all mobile subscriptions, is the implementer of the acclaimed m-Pesa service. Private-sector organizations are also spearheading the use of the most advanced technologies, including big data, analytics, and artificial intelligence. Such technologies are currently used by only 2% of all producers in Kenya, and are unfamiliar to most development and research professionals in the field.[38] These cutting-edge organizations primarily offer supply management, traceability, or on-farm data services.

Public sector and non-profit organizations, in contrast, rely on well-established technologies for the services they provide; over half of all services in the country use mobile technology, and a significant portion are based on broadband Internet.

Notable recent project collaborations include:

- **Weather information services:** The World Bank, in collaboration with aWhere and KALRO, is financing the Kenya Agriculture Observatory Platform, which seeks to provide real time weather information at the sub-county level to support farm management decisions.[39]
- **Financial services:** MasterCard, together with Mercy Corps, is funding the AgriFin Accelerate program to enhance financial inclusion for small-scale farmers using mobile technologies.
- **Production:** USAID, through its Feed the Future initiative, is financing the Connected Farmer Alliance, which, in collaboration with TechnoServe and Safaricom, is aiming to develop sustainable digital agriculture solutions to improve productivity.[40]
- **Inputs:** Safaricom, together with Mercy Corps seeks to offer farmers financial solutions and linkages to input supplies through the Digifarm platform.

38 Center for International Agricultural Research, Kenyan digital agriculture stakeholder workshop.

39 Kenya Agricultural and Livestock Research Organization, "Kenya Agricultural Observatory Platform."

40 TechnoServe, "Connected Farmer Alliance."

Challenges for digital agriculture

Important gains have been made in establishing digital infrastructure in Kenya, but a majority of the country is still not connected to mobile or broadband Internet service. Even for those in coverage areas, connectivity subscriptions and technology devices often remain out of reach.

Digital literacy is a major barrier to large-scale adoption of digital solutions. The usage of innovative features beyond SMS[41] remains minimal. A tiny minority of professionals in the country are prepared to proficiently use and maintain back-end service operations such as data management, blockchain, machine learning, IoT,[42] GIS,[43] and drones. Consumer digital literacy for front-end mobile and web interfaces is also low. Ironically, digital literacy rates are lowest in the producer hub, which also requires the most sophisticated levels of information to make informed management decisions and identify deviations from historical trends. In order to access this level of information, comparably sophisticated digital literacy levels are required. This is perhaps the first step toward a digital transformation of Kenyan agriculture, as it enables or prevents the success of most digital solutions. Similarly, the number of digital workers prepared to develop and manage digital solutions remains low, and is centralized in the largest cities. As such, there is significant opportunity for growth of the digital workforce, particularly in rural areas and the agricultural sector.

There is currently no policy framework to support efficient use and adoption of digital solutions in the agricultural sector. As such, issues of data ownership and security have yet to be addressed in the sector. Cyber security is an important issue nationwide; the Communications Authority of Kenya reported 10.2 million cyber threats in 2018 across all sectors.

41 Short Message Service.

42 Internet of Things.

43 Geographic Information Services.

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.[44] 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 Kenya can begin in earnest.

Technologies with greatest potential and their impact[45]

Several **cross-cutting** issues affect multiple hubs. These include a lack of decision support tools, poor market linkages, and a lack of product monitoring and traceability. **Mobile, database,** and **blockchain** technologies are the most promising in terms of addressing these challenges. These technologies can enable strong links between suppliers and consumers of inputs, raw agricultural products, and value-added products; transparent monitoring and traceability throughout the value chain; and robust decision support services. Mobile technologies are already available in many areas. In the short to medium term, more equitable mobile accessibility and the integration of database technologies are feasible. Blockchain may be integrated into the aforementioned systems in the medium to long term. (Figure 2)

Inconsistent demand and supply, as well as a lack of financial services, are the key limitations of the I**nput hub. Mobile, machine learning,** and **database** technologies offer the highest potential for addressing these issues. Advanced analytics and machine learning systems would enable input suppliers to consistently meet demand when and where it occurs. Mobile technologies would connect producers to essential financial services, such as credit,

44 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. Next, each technology was assessed across six dimensions: Progress (the current degree of development, use, maturity, scaling, uptake, and profitability of the technology), Policy and enabling environment (the degree to which policy, programs, and investments enable further development, adoption, and impact of the technology), Potential impact (the expected uptake and return on investments of the technology over the next decade), Efficiency (the extent to which the technology enhances food systems efficiency in terms of labor, inputs, yield, transport, and transaction cost reduction), Equity (the degree to which the technology breaks down barriers to equity, particularly in terms of youth and gender inclusivity), and Environment (the extent to which the technology supports environmental sustainability through waste reduction, greenhouse gas intensity reduction, and improved natural resource use efficiency). Each of these is assessed using a number of 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.

45 Disclaimer: These results are based on a combination of desk-research and on stakeholder consultation. The latter includes interviews with the government, farmers and farmers association, as well as a one-day workshop with key experts in the fields of Agriculture, Policy and/or Information Communication Technologies.

loan, savings, insurance, e-vouchers, and warehouse receipts. Good access to financial services gives producers the financial flexibility and risk mitigation necessary to invest in inputs, thus improving both demand consistency and equitable access to inputs. In the short term, systems based on simple technologies such as SMS / IVR[46] could be introduced relatively efficiently. In the medium term, as smartphones become more equitably accessible across all hubs, smartphone-based applications offering greater security and complexity will be possible. In both cases, health and environmental benefits could be realized by leveraging the system to distribute messages on correct and sustainable use of inputs.

The **Production hub's** biggest constraints are a lack of decision support, knowledge access, and mechanization. **Weather stations, data analytics,** and **machine learning** offer significant promise in terms of addressing these issues. These technologies would augment producers' resilience and adaptability in the face of climate volatility. Weather stations and weather forecasting already exist in Kenya as public services provided by the Kenya Meteorological Department. Significant investment and policies to strengthen their function will be needed for effective implementation of climate information and advisory services is to occur. There is also ample opportunity for public-private partnerships in building additional infrastructure and analytical capacity to support climate services. In combination with other site-specific decision support tools, timely, accurate weather services stand to substantially improve national agricultural productivity and GDP,[47] as well as reduce damages due to extreme weather. SMS/IVR[48] based systems are feasible in the short term. Several organizations, such as the CGIAR, have already developed simple advisory tools delivered through mobile SMS and data technology. These can be integrated with national and local weather and seasonal forecasting operations. In the medium to long term, advanced data collection and analytics, along with sustainable business models, would be meaningful additions to these programs. For larger farm operations, machine learning and precision agricultural equipment can also increase the efficiency of on-farm processes and decrease the intensity of environmental impact. Data analytics are relatively well supported by policy. However, the digital workforce needed to build and maintain them, as well as digital literacy necessary for their proficient use, is currently low.

46 Short Message Service/Interactive Voice Response.

47 Gross Domestic Product.

48 Short Message Service / Interactive Voice Response.

A lack of transparency, market data, and real-time communications are the major barriers facing the **Distribution hub. Mobile, advanced analytics,** and **database** technologies, hold the highest potential for addressing these challenges. High-value applications would include establishing market linkages for real-time producer-distributor communications and transparent monitoring and traceability systems. This would improve distribution processes and efficiency, as well as reduce postharvest loss and nutritional insecurity. In the short to medium term, mobile technologies are relatively accessible in terms of infrastructure, cost, and digital literacy, but will need to be enabled through investments and more efficient policies. By contrast, database management and advanced analytics have more support policy and investment support, but are still relatively costly and would require building stakeholder technical capacity in the medium to long run.

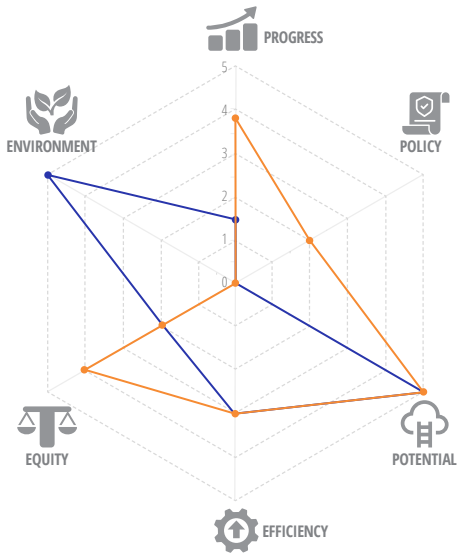
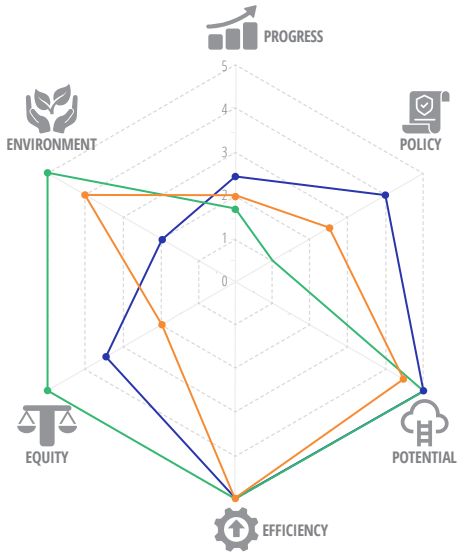
The **Consumer hub** is challenged by poor quality assurance and a lack of food safety information to support purchasing decisions. **Mobile** and **blockchain** technologies offer high-impact solutions to these issues in the short to medium term. Mobile technology is already relatively accessible in terms of infrastructure, cost and digital literacy, particularly in urban areas where consumers tend to purchase. Blockchain technology, is relatively inaccessible due to high costs and technical capacity requirements, but has already been prioritized in federal policy.

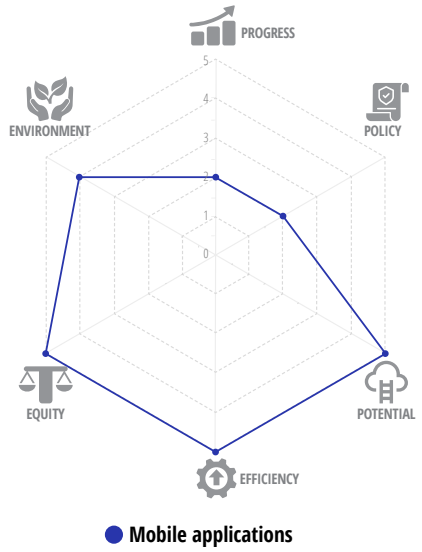
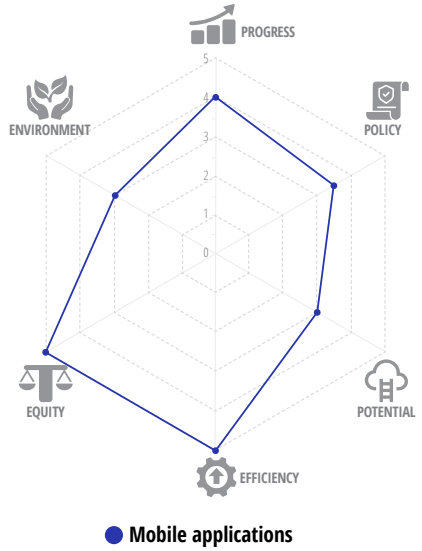
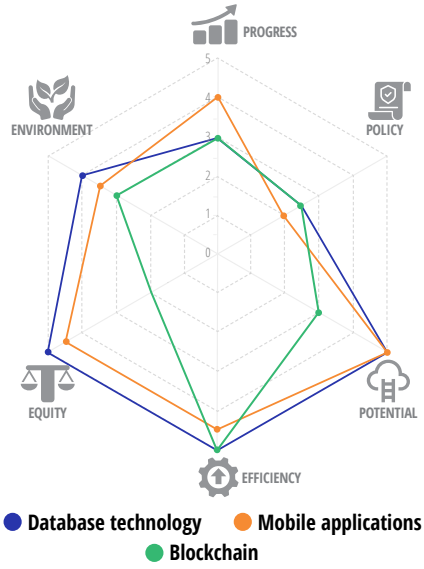
Potential avenues for the public sector

The increasing climate volatility facing farmers is likely the single greatest threat to the Kenyan agricultural sector. Weather information services are crucial to farmers foreseeing and preparing for extreme weather events. It comes as no surprise, then, that weather stations rank among the top four most promising digital agriculture solutions in Kenya. Weather stations rank poorly, however, in terms of profitability. Indeed, weather stations and weather services are generally public goods. As such, it is particularly crucial that the public sector provide timely, accurate weather data to Kenyan farmers nationwide. Similarly, electricity, broadband, and mobile connectivity are public services that largely rest in the hands of the public sector to establish and maintain. Improved infrastructural connectivity would enable weather and other data collection systems, which could then be shared via SMS/IVR.[49] Major crops should be prioritized in decision support development with an eye toward equity in terms

49 Short Message Service / Interactive Voice Response.

Table 1: Prioritized technologies

	Challenge	Technology	Outcome	Analysis
INPUT HUB	Volatile demand for inputs	**Machine learning for real-time information on demand**	Increased input sales and use; improved yields, and incomes	 Machine learning E-voucher subsidy systems
	Inefficient input subsidy system	**Mobile apps for input subsidies through e-voucher systems**	Increased input sales and use; improved yields, and incomes	
PRODUCER HUB	Lack of financial services	**Digitalized contracts and risk assessment models for optimal financial systems**	Innovation in agricultural production is enabled	 Digital contracts Machine learning Weather stations
	Low mechanization	**Machine learning for increased efficiency of on-farm processes**	Improved efficiency and reduced on-labor manual labor	
	Lack of information on weather and extreme weather events	**Weather stations for enhanced farm management decision making**	Increased resilience and adaptation in the face of climate volatility	

	Challenge	Technology	Outcome	Analysis
DISTRIBUTION HUB	Lack of market data and real-time communication	**Mobile applications for improved distribution efficiency and effectiveness**	Improved distribution processes, reduced postharvest losses and reduced nutritional insecurity	
CONSUMER HUB	Lack of information on food quality and safety	**Mobile applications for decision making in terms of food quality, origins, and safety**	Data-informed decision-making in terms of product consumption; enables producers of high-quality products to market and certify them as such	
CROSS-CUTTING HUB	Lack of decision support tools	**Database technology and advanced analytics for decision support**	Data-informed decision-making at all stages of the agricultural sector	
	Poor market linkages	**Mobile apps for connecting input suppliers, producers, distributors, and consumers for purchase and sales opportunities.**	Improved market linkages	
	Lack of product monitoring, traceability, and quality control	**Blockchain for traceability**	Improved product traceability and quality control	

of the populations served, particularly across genders. Universities and organizations such as FAO,[50] CGIAR,[51] World Bank, and NARE[52]S are well positioned to support the government in these efforts.

The dearth of distribution, storage, and value-add networks in Kenya has instigated problems of national interest. Food insecurity in some areas of the country is primarily due to poor food supply distribution from areas of high to low production. Additionally, a lack of infrastructure precludes the storing and processing of the bulk of products. As such, farmers are limited to selling during harvest, when there is an oversupply and prices are at their lowest. Subsequently, there is an overdemand period in which imported goods are sold at premium prices. Reducing postharvest losses and ensuring efficient distribution thus represent massive public opportunities to reduce malnutrition, increase agricultural incomes, and augment the national agricultural GDP.[53] Digital analytics of food system networks can effectively support decision-support systems for various stakeholders, as well as for infrastructure development.

Digital literacy is essential to sustainable digital solutions. As such, systematic capacity building across the Kenyan population will be crucial to the success of any digital solution. Many Kenyans, including rural residents, have used m-Pesa; this knowledge base may be a very helpful foundation on which to build additional digital literacy. Train-the-trainer programs across all education levels will lay the foundation for full use of the digital agriculture solutions put in place. In particular, digital literacy programs in workplaces, government offices, and universities will be crucial to ensure no generation is left behind. Public school programs can prepare future tool developers and trainers to enter the workforce and continue innovating digital solutions that leverage the level of technology access and literacy of most agricultural stakeholders, particularly producers.

The Kenyan National Information and Communication Technology MasterPlan, which highlighted topics such as farm data collection and e-learning platforms, expired in 2018. The country currently lacks a cross-sectoral master plan for digital solutions. The policies that remain in force, such as the National Broadband Strategy, support the development of general digital infrastructure. However, reestablishment of an overarching national strategy will help ensure coordinated efforts across all technologies, public institutions, and funding sources. Enforcement and integration of national strategies emphasizing the need for blockchain technology will help address and prevent cybercrime.

Additionally, while the Kenyan policy environment acknowledges the potential of digital solutions in many sectors, it stops short of paving the way forward for digital agriculture solutions, most notably in terms of mobile technologies. Development of a national digital agriculture strategy that articulates plans for each technology, each product value chain, and for monitoring and evaluation, will facilitate program ownership, funding, legislative enforcement, coordination efforts, and conscientious program design within the agricultural sector.

Explicit equity requirements will be crucial to the success of such policies. Strong policy is often necessary to catalyze financial organizations into developing and scaling financial services tailored to the unique needs of agricultural stakeholders. Digital agricultural solutions significantly lower the barriers to the implementing of such services by accurately measuring risk and by reducing the cost of expanding services into rural areas. For example, microfinance and insurance systems can be semi-automated using data analytics and drones; e-vouchers support subsidy, collateral, and warehousing systems; and computer modeling supports strategic distribution infrastructure and logistical decision-making.

A lack of finances for both purchasing technology and building digital capacity is likely the biggest barrier to the adoption of digital agriculture in Kenya. Prioritizing the 10% budget allocation for agriculture articulated in the Malabo Declaration will be a major achievement in this regard. Similarly, enforcement of existing tenure policy, and reconsideration of trade policies that have proven disadvantageous to Kenyan farmers, will help create an enabling policy environment for the agricultural sector in general.

Piloting, demonstration plots, and public awareness campaigns will help ensure that all stakeholder hubs and entrepreneurs are familiar with the digital innovations, solutions, and opportunities available to them.

Potential avenues for the private sector

The private sector's position at the cutting edge of Kenyan digital innovation will continue to be crucial in popularizing and monetizing new technologies. Given the very low digital literacy for advanced technologies such as database and blockchain, it will likely be in the hands of the private

50 Food and Agriculture Organization of the United Nations.

51 Consultative Group on International Agricultural Research.

52 National Agriculture Research and Extension Systems.

53 Gross Domestic Product.

sector to spearhead capacity building as they move such technologies forward. Additional entrepreneurial incubator programs, including those already provided by organizations such as PivotEast and Apps4Africa, will help to ensure that innovative solutions and strong business solutions continue to be developed.

Organizations such as Safaricom, Mastercard, PivotEast, and TechnoServe are already engaging in meaningful public-private partnerships to advance digital agricultural solutions in Kenya. The continuation of such efforts, and the engagement of other private-sector actors, such as Apollo and Twiga, will help bring practical digital solutions to stakeholders at economies of scale, and catalyze public-sector establishment of nationwide mobile and broadband services. Public-private partnerships with international public organizations with a focus on pre-competitive research will be particularly helpful in developing strong business models and quickly scaling up innovative digital agriculture solutions.

Outlook / synthesis of recommendations

Kenya has made marked progress in laying the foundation for digital agricultural solutions. Connectivity is expanding, subscription rates are increasing, and the cost of access is falling. A number of digital solutions in agriculture have been piloted over the last few years. This suggests important opportunities for digital solutions to several major challenges plaguing Kenyan agriculture, including poor access to crucial services; supply chain traceability and management; agricultural mechanization; and product quality assurance. The digital agriculture ecosystem is growing rapidly. However, real success thus far is marginal, and significant challenges persist. Cost remains high, access is still limited, and digital literacy remains very low.

Our research suggests that stakeholders who focus their efforts on developing mobile, database, blockchain, and weather station -based solutions are most likely to bring high-impact solutions to the Kenyan agricultural sectors. In all cases, piloting, demonstration plots, and public awareness campaigns will help ensure that farmers remain abreast of the digital innovations, solutions, and opportunities available to them.

Supportive national policy strategies; a public-sector commitment to foundational infrastructure; the support of the donor community; and private sector engagement will all be crucial to ensuring the success of such solutions.

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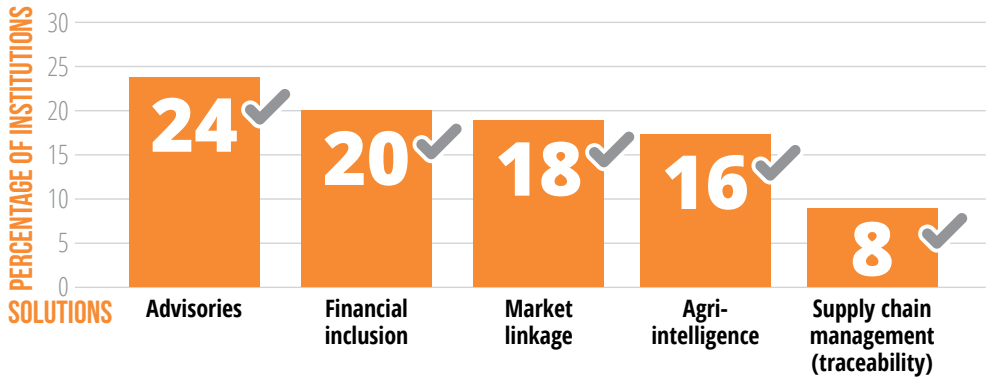
Annex

Table 2: Digital infrastructure and technologies definitions and examples

Technology	Description	Applications	Examples
Mobile	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 touchscreens, while feature phones do not	• Information, knowledge sharing, and advisories on weather, extension, early warnings, pricing, market supply and demand • Financial services such as credit, loan, payment, and vouchers • Digital receipts, records, contracts • Market linkages e.g. input access, real-time communications between stakeholder hubs, equipment rentals, product monitoring and tracing	• Kenya Agricultural Observatory Platform weather forecasting and analytics • WeFarm pricing, loans, inputs access • National Livestock Marketing Information Systems livestock volume and price information • Farm Drive access to credit and investment • Sokopepe Ltd communication platform • M-Pesa financial transactions
Broadband Internet	Internet infrastructure that is always on, and that delivers a minimum of 5 megabits per second (mbps) to homes and businesses for high speed access to voice, data, video and applications for development	• Extension and information services • Digital records • Market linkages	• National Farmers Information Service extension graphics, audio, and video • True Trade Africa digital trading records and market linkages • Kenya Agricultural Information Network • National Horticulture Market Information System
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 • Early warning systems	• Kenya Agricultural Observatory Platform weather predictions • Technobrain extension • UjuziKilimo precision farming and market information • Twiga finance support systems and produce access • Iprocure traceability and market linkages
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	• Water Watch Cooperative crop disease alerts • Once Sync Ltd smart contracts and recordkeeping • Apollo Agriculture financial, inputs, and extension services

Technology	Description	Applications	Examples
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	• Sunculture solar powered efficient irrigation • Arinifu chick health early warning • One Acre Fund soil monitoring and early warning systems • Agrocares extension • Kilimo Salama financial services
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	• Agrics Ltd automated payout drought index insurance • - Cellulant smart contracts • - Capture Solutions loans and advances • - Selina Wamucii traceability, quality control
Drones	Small remote-controlled aircrafts with no human pilot onboard	• Farm health evaluations • Tailored extension services	• Apollo Agriculture aerial on-farm data collection
Weather stations	Permanently installed devices that detect weather metrics, e.g. precipitation, temperature, wind speed, humidity, and pressure	• Weather forecasting • Early warning systems	• Kenya Meteorological Department weather forecasting
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	• Lantera Ltd precision agriculture • Bayer information sharing • Water Watch Cooperative crop disease alerts • Oakar Ltd crop health monitoring, resource mapping

Figure 1: Most common digital agriculture services in Kenya



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