TECHNICAL BROCHURE

TECHNOLOGIES AND DIGITAL SOLUTIONS FOR ACP HORTICULTURE

JUNE 2022

Funded by the European Union

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Citation : FFM-SPS Programme (2022) *Technologies and digital solutions for ACP horticulture.* Fit for Market - Strengthening sanitary and phytosanitary systems of the ACP horticultural sector (FFM-SPS) programme. Brussels: COLEAD.

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ACRONYMS

ACP	African, Caribbean and Pacific
AI	artificial intelligence
API	application programming interface
AU	African Union
B2B	business-to-business
B2C	business-to-consumer
B2G	business-to-government
CORS	continually operating reference stations
CSIRO	Commonwealth Scientific and Industrial Research Organisation
D4Ag	digitalisation for agriculture
DAgRI	Digital Agriculture Readiness Index
DSS	decision support system
ECA	Economic Commission for Africa (United Nations)
FAO	Food and Agriculture Organization of the United Nations
GIS	geographical information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GSMA	Groupe Speciale Mobile Association
ICTs	information and communication technologies

ICT4Ag	information and communication technologies for agriculture
IoT	internet of things
IPM	integrated pest management
IT	information technologies
IVR	interactive voice response
LAI	leaf area index
LAN	local area network
LIDAR	light detection and ranging
LMIC	low- and middle-income country
LoRaWAN	low-range, wide area network
LTE	Long-Term Evolution
ML	machine learning
MNO	mobile network operator
NDVI	normalised difference vegetation index
NFC	near field communication
NIR	near infrared
NoSQL	non-Structured Query Language
OBD	outbound dialer
P2P	peer-to-peer
PDA	personal digital assistant
PRIDA	Policy and Regulation Initiative for Digital Africa (EU)
QR	quick response (code)

RFID	radio frequency identification
RS	remote sensing
RVI	radar vegetation index
SAR	synthetic aperture radar
SMS	short message service
SQL	Structured Query Language
UAV	unmanned aerial vehicle
USSD	unstructured supplementary service data
UX	user experience
WAN	wide area networks
WiFi	wireless fidelity
WLAN	wireless local area network

Note

Given the pace of development, information on mobile technologies can rapidly become outdated. This publication is based on findings in 2021.

SUMMARY

Information and communication technologies for agriculture aim to improve the effectiveness of production and the sustainability of agribusinesses, farmers and ecosystems. Access to these technologies in African, Caribbean and Pacific (ACP) regions has changed with the emergence of mobile phones – most farmers worldwide now have at least a simple phone, and smartphone penetration is increasing rapidly. Smallholders throughout the world can access market prices, e-advisory services for information about possible pests and diseases by SMS, and community radio broadcasts and training videos to learn better agricultural practices. Within the agri-food industry, traceability and certification are no longer imaginable without information technologies and tools for better management.

This report analyses existing SmartTech solutions for horticultural value chains in ACP countries. Following an introduction explaining the terminology and available technologies, the document focuses on relevant use-cases and solutions. SmartTech solutions from high-income countries are included only where no solutions from ACP countries are available, or where the solutions are of high interest.

The SmartTech use-case clusters featured here are:

- Advisory services
- Remote sensing
- Farm management
- Transportation and storage
- Digital supply chain management and traceability
- Artificial intelligence and machine learning
- Sensors for surveillance of soil and water parameters
- Smart traps for IPM
- Drones for pest/disease control and surveillance
- Drones for mapping areas and crop productivity
- Automated irrigation
- Blockchain for traceability and trust
- Agricultural intelligence for end users

The technologies covered address mainly the following target groups:

- Smallholder/commercial farmers
- Communities/cooperatives
- NGOs/implementers
- Extension services/technicians/village-based agents
- Agrodealers
- Aggregators/off-takers
- Processing industry
- Transport sector

The remainder of the document addresses risks and challenges for the implementation of SmartTech solutions in the ACP horticultural context, and the keys to success. Risks may be social, technological and financial. Reliable access to electricity, technology and networks in rural areas; and affordability of equipment and broadband internet are as critical to the success of the digital transformation as the necessary digital literacy of all stakeholders, especially smallholder farmers. A

low level of locally available ICT expertise, the risks of data misuse and a general scepticism about the introduction of new technologies is hindering the process. The development of this sector needs support through public policy, but the level of digital readiness varies greatly between countries. While transformation of the sector must be intrinsic and cannot be forced, governments can stimulate development in various ways by promoting enabling environments.

The main keys to successful deployment of AgriTech in ACP regions, described in section 7 of this report, are:

- Keep it simple for the end user
- Select the appropriate technology
- Create sustainable and affordable solutions
- Consider the local setting
- Attract young people to modern farming
- Mobilise local ICT capacities
- Make use of existing solutions where possible
- Use local products with local support
- Develop a feasible business model
- Find and create synergies

1. INTRODUCTION

Information and communication technologies for agriculture (ICT4Ag), e-Agriculture, digitalisation for agriculture (D4Ag) and SmartTech4Ag are similar technological fields that aim to improve the effectiveness of agriculture and the sustainability of agribusinesses, farmers and ecosystems. While this rapidly developing technology sector integrates each new technology as soon as it comes up, smallholder agriculture in African, Caribbean and Pacific (ACP) Member States frequently still follows traditional practices. Farmers in Europe and the USA might already operate their own drones to monitor crop health, while smallholders in Africa and Asia cannot access the seeds they need for the next planting season.

Access to technology changed with the emergence of mobile phones. Most farmers worldwide now have at least simple phones, and smartphone penetration is increasing rapidly. Smallholders throughout the world use SMS to get market prices, weather alerts, or to share machinery and irrigation equipment. They use e-advisory services to get information about possible pests and diseases; and they listen to community radio broadcasts and training videos to learn about better agricultural practices. But the question is: how can the last mile to smallholders be bridged so that they can benefit from hi-tech solutions without needing to understand the underlying complex processes, and without access to the latest technologies?

Within the agri-food industry, traceability and certification are no longer imaginable without information technologies and tools for better management. The rise of Big Data, artificial intelligence (AI), machine learning (ML), blockchain, drones and Geo-IT brings new potentials and exciting solutions for agriculture in general – and for horticultural value chains in ACP countries.

COLEAD's Digitalisation Strategy aims to:

- **Increase awareness of technological developments and prospects of interest to the agri-food sector**
- **Link farmers and processors with research and ICT start-ups to implement or scale solutions**
- **Create case studies / implement pilot projects to increase knowledge regarding the opportunities offered (B2B and B2C) by innovative ICT solutions applied to ACP supply chains**
- **Upscale ICT-driven successes through increased funding and investment**
- **Provide capacity building on ICT tools with direct benefits along the chain from farm to fork**
- **Build capacity in IT and web-based solutions to create simple local marketplaces (online and offline) for COLEAP members.**

This report presents a situation analysis of existing SmartTech solutions for horticultural value chains in ACP countries. It provides an overview of available solutions, their underlying technologies, and potential hurdles and barriers to their implementation. The report focuses on hi-tech solutions, including ML, AI, blockchain and geospatial technologies, for which literature exists on extension, farmer registration, e-finance and insurance solutions. This is a different approach from other studies (e.g. CTA's *Digitalisation of African Agriculture Report:* Tsan et al., 2019) that focus on lower-tech approaches such as SMS, radio and simple apps.

The first section introduces ICT terminology and explains the available technologies. This section can be safely skipped by those who already have a robust expert knowledge of ICT.

The body of the document reports on the status of SmartTech for agriculture in the ACP countries. Selected use-cases are presented for the value chain elements identified, and solutions are described with resources and further reading. The key information sources for the use-case examples are:

- *AgriTech Deployment Tracker* (GSMA, n.d.a) – note that a large proportion of the applications listed relate to areas other than agriculture
- *The Digitalisation of African Agriculture Report, 2018–2019* (Tsan et al., 2019) – a rich source of applications with recommendations and a good overview on policies and regulations (the related CTA Apps4Ag database, www.Apps4Ag.org, is no longer updated from the end of 2020).

CTA's *ICT Update* series also provides useful information, including the following:

- Mapping. *ICT Update* 54 (2010).
  https://cgspace.cgiar.org/bitstream/handle/10568/91663/ICTUpdate54E.pdf
- Small islands and e-resilience. *ICT Update* 71 (2013).
  https://cgspace.cgiar.org/bitstream/handle/10568/75312/ICT071E_PDF.pdf
- eAgriculture Strategies. *ICT Update* 73 (2013).
  https://cgspace.cgiar.org/bitstream/handle/10568/75314/ICT073E_PDF.pdf
- Linking farmers to markets. *ICT Update* 77 (2014).
  https://cgspace.cgiar.org/bitstream/handle/10568/75318/ICT077E_PDF.pdf
- Data revolution for agriculture. *ICT Update* 79 (2015).
  http://publications.cta.int/media/publications/downloads/ICT079E_PDF_QElaTCG.pdf
- Youth e-agriculture entrepreneurship. *ICT Update* 83 (2016).
  https://cgspace.cgiar.org/bitstream/handle/10568/89782/ICT083E_PDF.pdf
- Open data benefits for agriculture and nutrition. *ICT Update* 84 (2017).
  https://cgspace.cgiar.org/bitstream/handle/10568/89784/ICT084E_PDF.pdf
- Unlocking the potential of blockchain for agriculture. *ICT Update* 88 (2018).
  https://cgspace.cgiar.org/bitstream/handle/10568/97525/ICTUpdate_88EN.pdf
- Women and ICT in agriculture. *ICT Update* 90 (2019).
  https://cgspace.cgiar.org/bitstream/handle/10568/99720/ICTUpdate90E.pdf

The list of use-case examples cannot claim to be comprehensive, but is intended to be as complete as possible. SmartTech solutions from high-income countries are included only where no solutions from ACP countries are available, or where the solutions are of high interest. The selection of solutions focused on horticultural value chains, specifically:

- soil analysis and advice
- irrigation solutions
- plant health, integrated pest management (IPM) and surveillance
- productivity monitoring
- processing
- transport and storage
- export and trade
- traceability (all value chain steps).

2. TECHNOLOGY LANDSCAPE

Information and communication technology in agriculture (ICT4Ag), digitalisation for agriculture (D4Ag) and e-agriculture are synonyms for the integration of electronic technologies into agriculture and related fields. The number of available technologies is large, and new ones are constantly being added. This document does not claim to be complete in either depth or breadth. It focuses on technologies that are important in the context of horticultural value chains, and highlights innovations with the potential to promote climate-smart development.

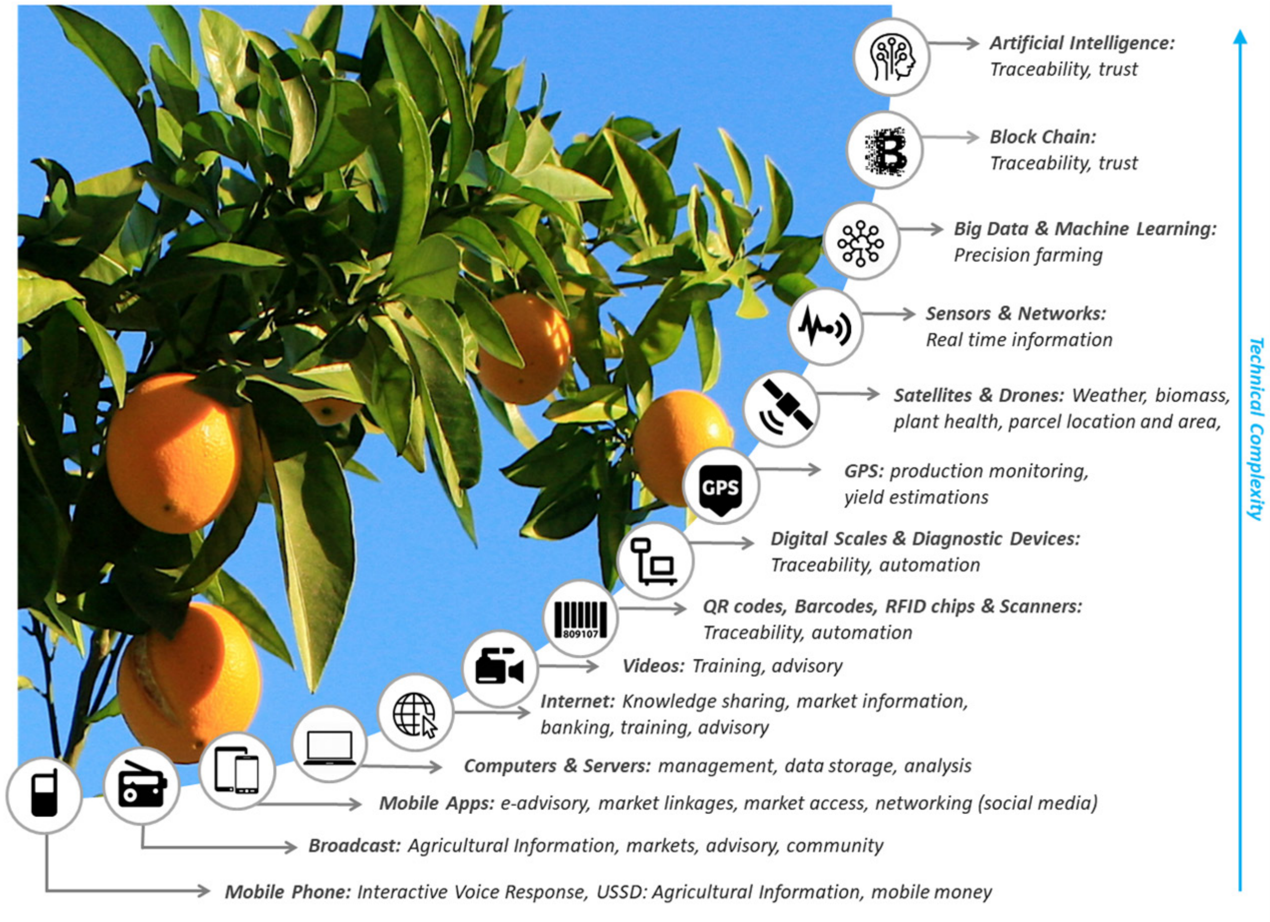


Figure 1 The complexity and applicabilityof ICTs for digital agriculture

2.1 Hardware devices

2.1.1 Personal devices

- A classic cell phone is the simplest and cheapest type of mobile end device. It is used for making phone calls, and sending and receiving SMS and voice messages.
- Some devices already have an integrated camera, calendar, etc., but those are difficult to handle as the keyboard is limited.
- A feature phone extends these functionalities by adding a better screen, a full web browser and optionally a Global Positioning System (GPS).

- A smartphone is a high-end mobile device. With specific operating systems (e.g. Android) and LTE/4G/5G internet speed, they are closer to a computer than to a feature phone. Modern smartphones feature a large touch screen, Wi-Fi connectivity, high-definition (HD) camera, Bluetooth wireless technology and GPS.
- Of particular interest for the agricultural sector are niche sensor technologies, such as temperature, humidity, barometer, light and NFC sensors, that may be installed on certain smartphones.
- Smartphones allow users to edit documents, use social media, handle email and create spreadsheets. They can be used as a navigation device, and as a music and video player. They can run third-party programs and thus be configurable to any personal need.
- In Europe the smartphone is now the standard option, while in Africa their use is still limited as prices are comparably high both for the device[1] and for the data (Figure 2).

- A personal digital assistant (PDA) is a pocket computer, very similar to a smartphone, but usually operated with a small keyboard and a pen. A PDA does not necessarily offer mobile phone features.

1 According to IDC, 80% of the smartphones sold in Africa were in the low end category, below US$200. https://www.idc.com/getdoc.jsp?containerId=prMETA47840421

- A tablet is a small computer, larger than a smartphone, usually with a very responsive touch screen. They all have WiFi, frequently also mobile data, but rarely have a GPS. Like a smartphone, a tablet runs a mobile operating system and thus allows the running of third-party software.

- A computer – desktop or notebook/laptop – still plays the main role in office workflows, enabling word processing, communication, spreadsheets, designer software and database applications.
- Specific software for modelling, mapping and image-, audio- and video-processing is usually developed for computers.
- Computers are very flexible and can easily be extended by sensors, additional monitors, input devices, scanners and printers.
- In the African context, notebooks have the great advantage of running on battery in case of a power outage. For particularly dirt-intensive environments, there are robust solutions with casings, keyboards and touch screens that are insensitive to dirt and water.

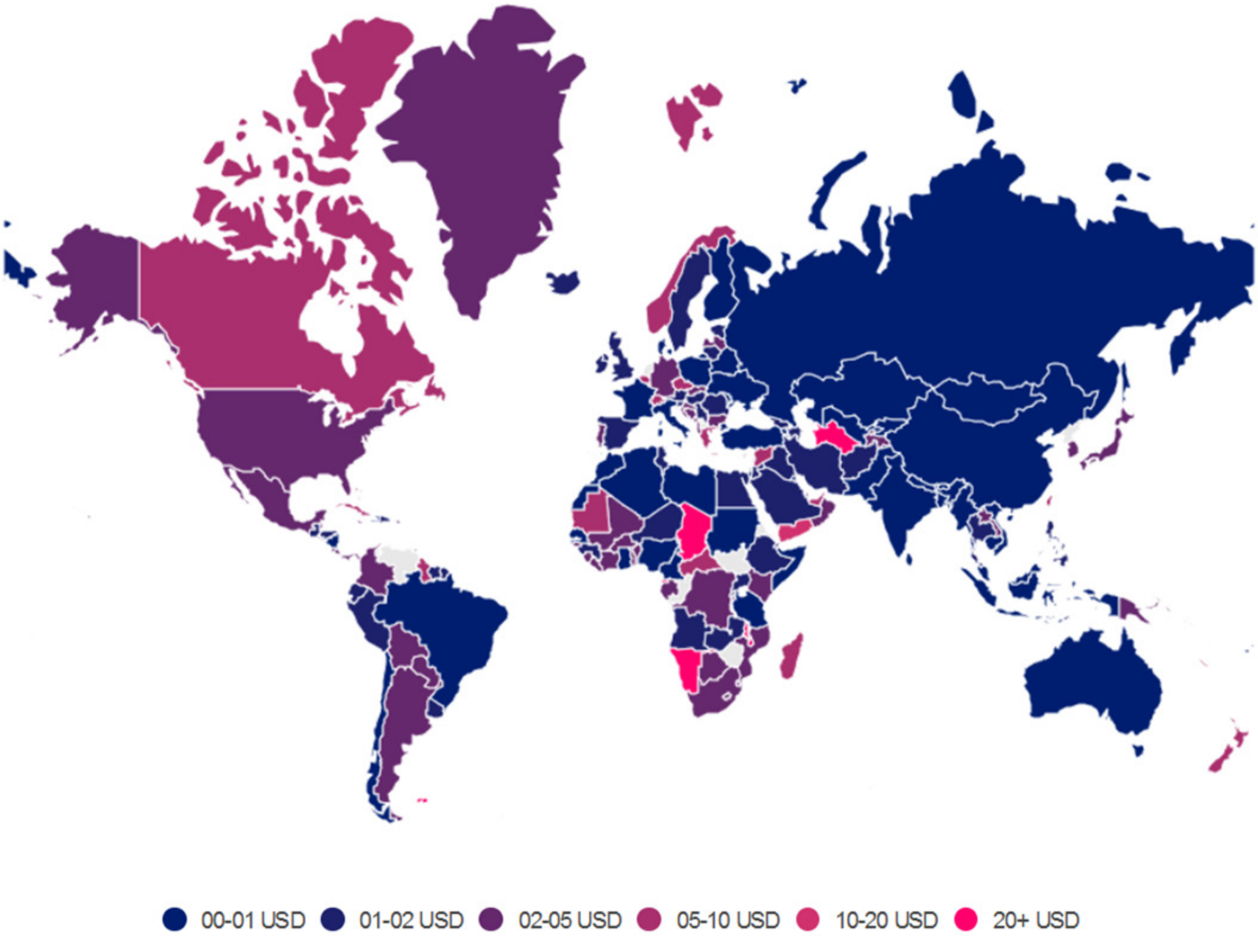


Figure 2 Worldwide mobile data pricing: prices for 1 GB data download. Source: Cable.co.uk (n.d.)

2.1.2 Sensors and GPS

A sensor is a hardware device that detects events or changes in its environment and communicates information to other electronics for processing. Various environmental parameters can be automatically measured, such as humidity, pressure, temperature, wind speed and light. In the agricultural context, sensors are used for meteorological observation; to monitor water level, flow and quality; and to quantify biomass to detect water stress or infestations, for example. Sensors can measure soil parameters, chemical residues, or simply the weight of produce. The dairy sector uses sensors to measure temperature, weight and the fat content of milk. In livestock, sensors observe animal health and herd movement. Sensors are key to automation and therefore a valuable component of the digitalisation of agricultural processes.

A camera can be considered as an optical sensor, and digital image processing can make visible information that cannot be detected by the human eye.

While most sensors operate from a fixed position, a GPS sensor does the opposite: it measures the three-dimensional position on Earth or in space. Four systems are available: the US Navstar-GPS is the oldest; the Russian GLONASS and Chinese BeiDou are recent developments; and the European Galileo system has the highest accuracy, up to 10 cm precision everywhere on Earth. Modern GPS chips can operate with a mix of these signals. Altitude values usually are less accurate, but the operation of base stations with differential GPS or correction by continually operating reference stations (CORS) allows millimetre precision.

2.1.3 Remote sensing

Remote sensing (RS) is the science of observing the Earth from the sky, using sophisticated sensor technologies mounted on satellites, airplanes or drones to record various physical parameters. Multi-band images deliver not only colour images of the visible light, but also invisible bands such as infrared and ultraviolet. This allows the mapping of crop type, crop density, land degradation, crop health, and other parameters. The combination of different bands allows determination of the spatial distribution of physical parameters such as temperature, humidity or the different vegetation indices. For instance, the normalised differential vegetation index (NDVI) quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). This helps to identify biomass, water stress, pest infestations and other indicators, and thus to improve crop health.

Laser-based sensor technologies, such as light detection and ranging (LIDAR), can help to monitor the crop height and leaf area index (LAI) of plantations and forests. Synthetic aperture radar (SAR) sensors measure crop moisture, soil moisture and crop indices (radar vegetation index, RVI) and are able to penetrate the clouds: radar does not depend on reflected sunlight, but sends out its own energy pulse and measures the return signal (backscatter) after interaction with the surface.

These technologies use coordinate systems to make the data visible on topographic maps or to overlay, merge and intersect these data on/with other data sources (Figure 3).

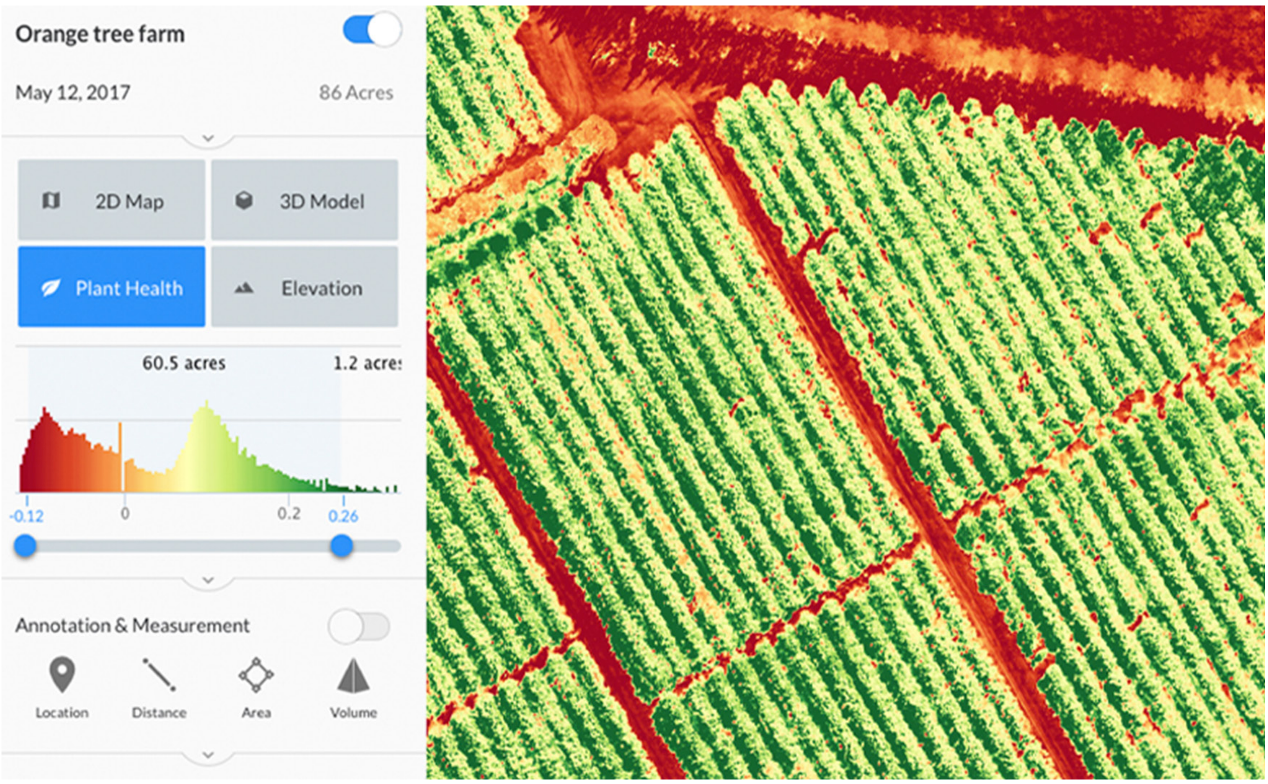


Figure 3 NDVI of orange tree farm in South Africa. Source: Witte (2018)

Remote sensing technologies can be used to estimate agricultural areas, crop yields and crop health. On a larger scale, monitoring technologies can help to evaluate environmental impacts. Water use and resulting resource depletion can be monitored remotely, as well as other impacts such as erosion and biodiversity loss.

Satellite data usually is very expensive, especially if the images are taken on demand. However, more and more satellite data is becoming available free of charge (e.g. MODIS, Sentinel 1 and 2, Landsat 7-8, SPOT 5-7). Ground truth data usually is necessary for calibration in order to derive quantitative results. While satellites follow their orbit and therefore pass a specific area in a defined interval, airplanes and drones can be operated on demand. Drones can be flown very low, so are less sensitive to weather events and result in a higher image resolution.

Based on the data obtained, remote sensing technologies can provide crop classification maps, land-use maps, digital elevation models and many more. They can help to detect the nearest open-water pond, or the most easily accessible grazing grounds. Livestock welfare can be monitored by mounting sensors on collars worn by the animals. However, these technologies are expensive, sensitive and need a high level of expertise for operation and data processing.

Geographical information systems (GIS) are special database systems that can handle spatial data in two- and three-dimensional space. They have become indispensable in agriculture for monitoring, forecasting and decision support. They usually run on computers with large screens and colour printers attached, but light systems are also available for tablets and smartphones, mainly for mobile data collection. They serve for the preparation of maps, but they also support all sorts of geospatial analyses such as the calculation of population densities, tracking of animals, management and monitoring of the environment, routing of multi-modal transport, and so on. They are very useful for understanding spatial relationships and making them comprehensible via maps (Figure 4).

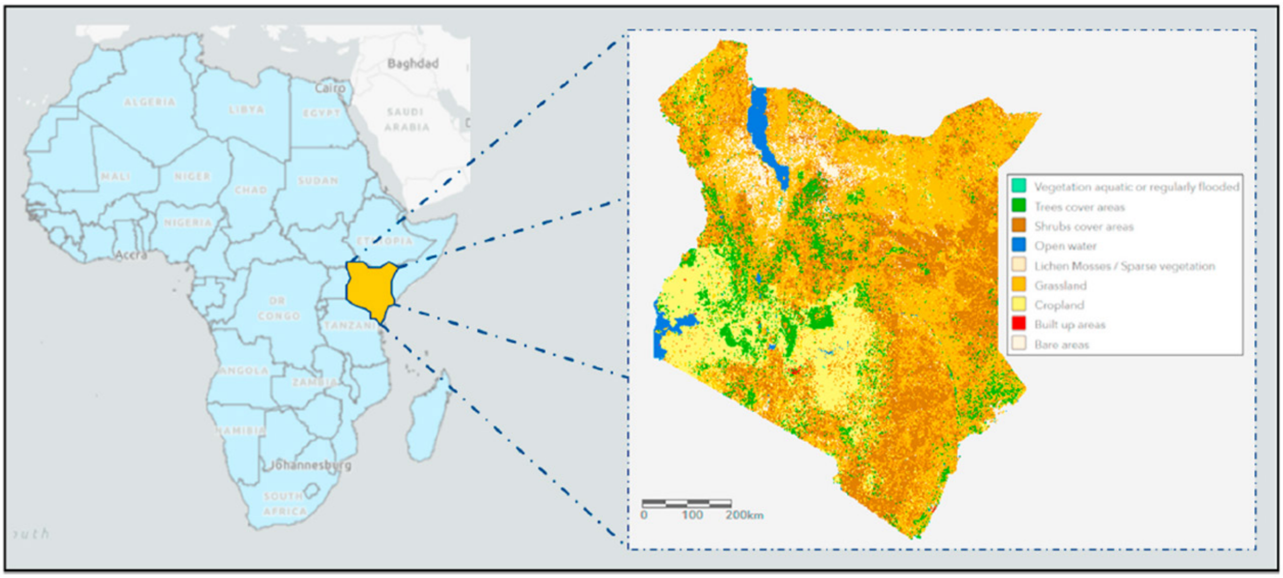


Figure 4 Kenya land cover map, highlighting key land uses. Agricultural cropland regions may provide biomass resource opportunities for development of the bioenergy sector. GIS map at 20 m over Africa based on 1 year Sentinel-2A observation data. Sources: image, Welfle et al. (2020); data, ESA (2016)

2.2 Information storage and exchange

Databases are at the core of any ICT system. They help to structure, organise, store and analyse huge amounts of information produced by ICTs. A database management system offers the tools that enable users to interact with the data. The "back end" hosts and structures the data, and the "front end" provides an interface for the user's interactions with the data. Relational database systems are well structured with interlinked tables, while NoSQL (non-Structured Query Language) databases can be as simple as a data repository. In modern systems, the data is centrally hosted on one or more servers (which may run in the cloud), and accessed by the user via a website or mobile app, using different devices. This is an example of three-tier architecture, which organises applications into three logical and physical computing tiers: the presentation tier or user interface; the application tier where data is processed; and the data tier where the data is stored and managed. (Note that Microsoft Excel lacks this type of data structure – it is a spreadsheet, not a database.) An information system adds people (users), roles and tasks to the technical database and thus adds value to the collected information. An information system that supports business or organisational decision-making activities is called a decision support system (DSS).

With the emergence of phones and smartphones, access to technology changed. Most farmers nowadays have at least simple phones, and smartphone penetration is increasing rapidly. Smallholders worldwide use SMS services to get market prices and weather alerts, or to share machinery and irrigation equipment, and they use e-advisory services to get information about possible pests and diseases. ICT can help to streamline the dissemination of information, especially if the number of recipients is large.

2.3 Communication

2.3.1 Bulk SMS messaging

Bulk SMS messaging allows the dissemination of SMS messages to large numbers of mobile phones. All recipients may receive the same message, but bulk SMS messaging also makes it possible to send customised messages providing individual, localised content, such as local weather forecasts and alerts for a given farm area, or sales figures for a given farm. Bulk SMS messages can be realised either by using the website of an SMS service provider, or by installing desktop software that communicates with an SMS gateway. Both solutions allow uploads of as many phone numbers as required. Some desktop software allows scheduling for sending messages at specific times and/or to a specific group of recipients, based on the criteria available in the farmer registry (e.g. by gender, value chain, region, etc.). Bulk SMS messaging makes it possible to automate and localise weather forecasts, to send farmers timely reminders to apply fertiliser, or to send individually configured SMS messages listing the amount of milk delivered by the recipient farmer during the current week.

2.4 Voice mailing

In case of low literacy among the recipients, voice mailing (also known as outbound dialer, OBD) can replace bulk SMS messaging. In this case, pre-recorded audio messages are sent to a large number of recipients. This approach is similar to bulk SMS messaging, except that it does not allow automatic configuration of customised messages to individual farmers. However, the administration of a voicemail system is more complex as the messages must be pre-recorded before they can be sent. The development of speech output systems has not yet progressed far enough for African idioms to be rendered in sufficient quality.

2.4.1 Unstructured supplementary service data

Unstructured supplementary service data (USSD) technology offers a means of bi-directional communication. USSD technology is well known by users of prepaid cellular phones as it allows them to query their available balance. This technology allows specific information to be provided to farmers on demand, by offering menus for selection. The farmer can dial a number and is then led through a menu, e.g. "for the weather forecast, press 3". This technology is much more complex and expensive than SMS services, as it requires a USSD server which has to be developed and maintained – usually by the mobile phone provider.

Interactive voice response (IVR) technology is similar to USSD in allowing callers to navigate to content using their voice. However, it is even more complex than USSD, as there are often several idioms spoken in the same region.

2.4.2 Video and audio

Video and audio are still a good approaches to training and learning. As literacy rates are usually lowest among smallholder farmers in remote areas, community radio and local television still play an important role in the dissemination of information. Nowadays, videos and audios can also be made available for on-demand streaming. Several web portals and apps offer videos and audios for various agricultural topics in several languages. To access this information, the end user needs a mobile device with large screen and a good internet connection. But once downloaded, videos can be shown to interested farmers in offline mode.

2.4.3 Transmission technologies

ICT offers a wide range of transmission technologies. Different generations of mobile networks offer different bandwidths and data transfer performance – although the newest are usually not instantly available in most African countries. General Packet Radio Service (GPRS), 3G, Long-Term Evolution (LTE), 4G and the new 5G are all standards for data transmission. But even the old GPRS allows the transmission of sensor data to servers. In emergency situations, mobile networks frequently break down and it is the old-fashioned radio transmitter which then still works (or the modern, but expensive, satellite data services). Wireless networks (WLAN or WiFi), local area networks (LAN), wide area networks (WAN) and derivates such as LoRaWAN (long-range wide area network) all offer their own technical advantages, and the appropriate technology can be found for each specific case.

2.5 Mobile apps, web apps and services

A mobile app (often simply called an app) is a program prepared for mobile devices such as Android, iOS or Windows phones or tablets.

A native app runs only on a specific operating system, meaning that an Android app cannot run on an Apple iPhone.

- A native app can run without internet access – it is an independent program which can run offline.
- A web app runs in a web browser and therefore needs a permanent internet connection.

Behind most apps there is a web server which communicates, at least from time to time, with the program on the mobile device.

All apps are made for a specific purpose. In the agricultural context, for example, there are apps available for (among others):

- farmer management systems
- diagnostics and advice (e-advice)
- weather and early warning
- market access
- market platforms
- training and learning
- traceability.

But many smartphone users currently only use the well-known social media apps (such as Facebook and WhatsApp).

2.6 ID technologies

Traceability, which is very important in the agricultural sector for certification and export, can be introduced or digitised using barcodes, quick-response (QR) codes, radio frequency identification (RFID) chips and the matching scanners, which help to uniquely identify farmers, animals or agricultural products. Farmer registries and livestock databases make use of these codes, and scanners, digital scales, tickets and stickers streamline processes and help to achieve traceability. The digitalisation of these processes enables traceability for large numbers of farmers and their products, and gives new insights into agricultural practices that can be valuable for their optimisation.

E-payment using smartphones, feature phones and optionally near field communication (NFC) chips can be made available to many users who previously had no access to bank accounts (Figure 5). Kenya has been a world leader in the adoption of mobile payments following the launch of M-Pesa in 2007. Sub-Saharan Africa is the region where mobile money is most widely spread (Figure 5), followed by Southeast Asia and Latin America (Runde, 2015).

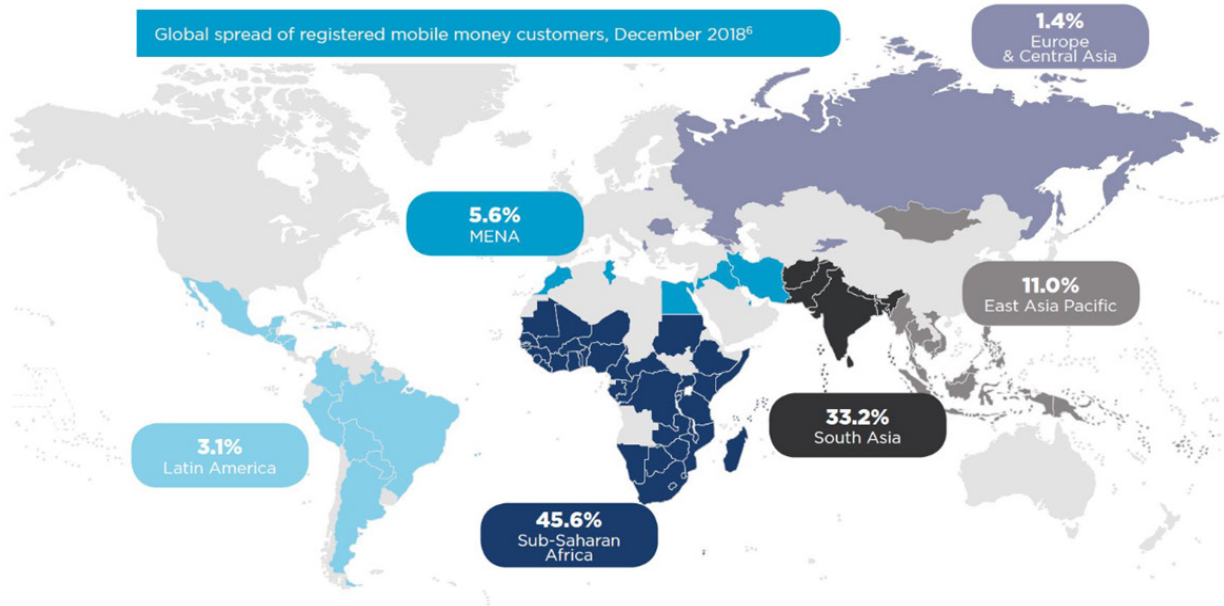


Figure 5 Global spread of registered mobile money customers 2018. Source: GSMA (2019)

The African Union (AU) Continental Agriculture Strategy provides an index for financial inclusion for agriculture (FIAG) which uses subsets of the World Banks Findex database and specifically considers financial indicators of the rural population (Figure 6).

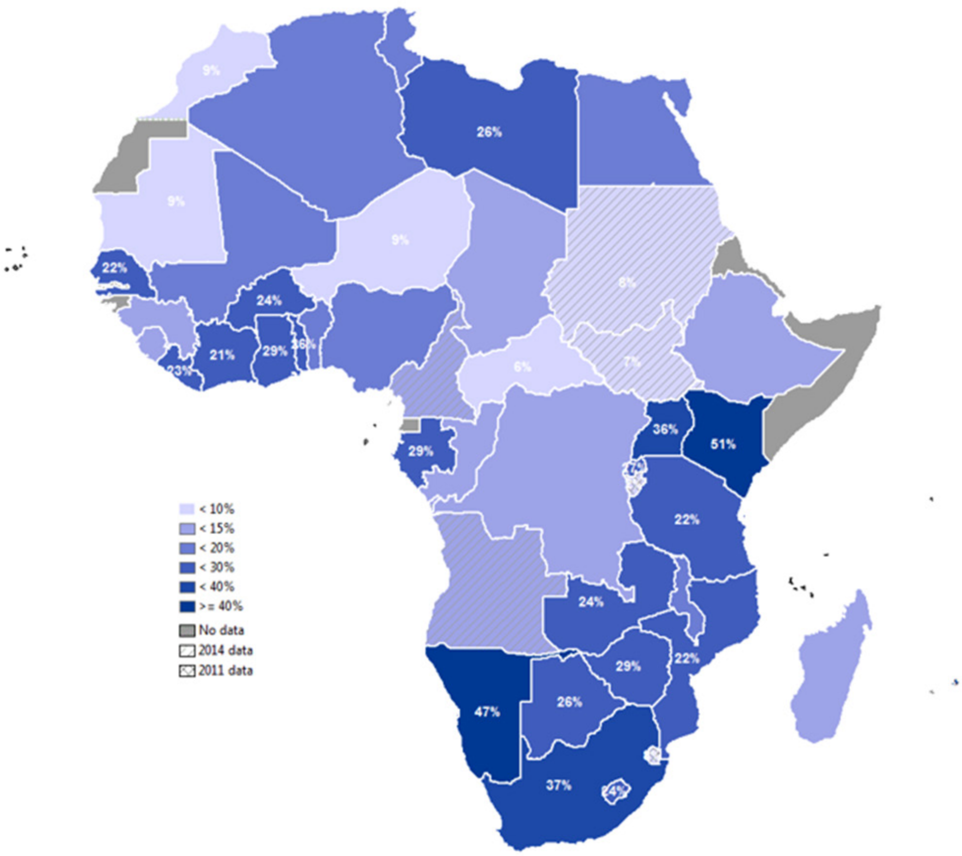


Figure 6 The AU Digital Agriculture Strategy's Financial Inclusion for Agriculture Index. Source: Elsaesser (2022)

2.7 Smart/high technologies

2.7.1 Blockchain, artificial intelligence and machine learning

- A blockchain is a continuously growing list of blocks of information, each of which contains the information of the previous block in an encrypted format. Thus a blockchain can hold information from different sources, and cannot (easily) be counterfeit or hacked. So blockchains are seen as possible means to introduce or strengthen transparency and trust.
- Artificial intelligence (AI) is a difficult term to grasp because it is constantly changing. It is applied to intelligence demonstrated by machines (computers), and is often used for any device and algorithm that mimics human learning behaviour. Classical examples are speech recognition and autonomously operating cars.
- Machine learning (ML) refers to computer algorithms that improve automatically through experience.

All three have their justification:

- blockchain technologies can introduce transparency and trust all along the value chain
- AI and ML help to derive sophisticated management data from the huge data sets provided by sensor networks
- AI and ML can enable hyper-localised weather forecasts and thus significantly enhance early warning systems
- ML-based apps (through background servers) can accurately identify related plant and weed species, and even related pest and diseases.

Blockchain, AI and ML risk being misused because they are frequently misunderstood as placeholders for modernity and innovation. These technologies are not a panacea for all kinds of problems – however, properly applied they can help alleviate or even solve many problems. But all three need high-performance computer processors, internet, storage devices and power supply. Thus the installation and operation of such systems is expensive and needs many resources.

2.7.2 Cloud computing

Cloud computing allows the outsourcing of these requirements to competent service providers. That way, an agricultural business can run databases and apps without expert computer knowledge or a dedicated IT department. Cloud computing offers a flexible way to allocate resources, and the location where the infrastructure is installed is irrelevant.

Through platform-as-a-service technology, farm agents might operate apps that directly communicate the collected data to a cloud-based database, where it is processed, analysed and made available for decision makers via a web portal. The farm managers then access this data via their computers or smartphone browsers. No data is stored in-house, no database has to be installed, and no experts are necessary to provide knowledge for maintenance of the system. The software developers can easily make updates and provide additional functionalities without the need for re-installation on several devices within the company.

2.8 Models and simulation games

Weather, plant and soil processes have been topics for modelling and simulations since computers have existed. Recent models include those for water balance, crop production, animal nutrient requirements, livestock herd dynamics, and the environmental impact of agriculture. Models play an important role in our understanding of complex relationships, and in the mitigation of various risks through early warning and decision support systems (DSS).

"Serious games" and simulation games try to "gamify" these complex relationships in order to make them easy for most stakeholders to understand, and to encourage behavioural change towards better management, better protection of the environment, and a fairer distribution of limited resources. Serious/applied games may be either board games or computer games that are designed for education or behavioural change, and not for pure entertainment.

2.9 Responsible data guidelines

Information technologies always deal with data. Data is collected, handled, stored, analysed and crossed with other data. It is distributed and made available to large user communities for a wide variety of purposes. Data can even be collected and processed fully automatically, and ML algorithms can draw conclusions and make decisions. Technology offers us all sorts of possibilities. Not all of these are smart, and not all of these have the good effects they are intended for.

The use of ICTs is associated with challenges and risks. Collected data can fully or partly concern privacy and personally identifiable information. The data producer is not necessarily the data owner, and data can be sold to third parties for suspicious purposes. All uses of data should respect and protect people's rights, and actions should be planned in a thoughtful way. A good regulatory framework is the best way to ensure responsible data handling by all parties.

"Responsible Data is a concept to outline our collective duty to prioritise and respond to the ethical, legal, social and privacy-related challenges that come from using data in new and different ways in advocacy and social change." (Responsible Data, n.d.). Many multilateral organisations and countries worldwide have developed guidelines for the responsible handling of data (see Box 1).

Examples of responsible data guidelines

- European Union: General Data Protection Regulation (GDPR), for all EU Member States (Intersoft Consulting, n.d.)
- Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ): Responsible Data Principles which can be applied whenever local data protection laws are absent (GIZ, n.d.; 2019)
- United Nations Office for the Coordination of Humanitarian Affairs: Data Responsibility Guidelines (UN OCHA, 2019)
- United States Agency for International Development: Considerations for Using Data Responsibly at USAID (USAID, 2018)
- Oxfam: Responsible Program Data Policy (Oxfam, 2015)
- International Committee of the Red Cross: Handbook on Data Protection in Humanitarian Action (Kuner and Marelli, 2017)

Guidelines tailored to the agricultural context:

- Global Open Data for Agriculture and Nutrition (GODAN) (Ferris and Rahman, 2016)
- CGIAR: Responsible Data Guidelines (Rodrigo, 2019)

Where there is weak or no regulation in a country, guidelines have to be developed or found elsewhere in order to avoid data misuse. In one example, toolboxes with step-by-step checklists are available from the Protection Information Management Initiative (PIM, n.d.).

3. SOLUTIONS FOR ACP COUNTRIES

3.1 Clustering approach for D4Ag solutions

The Member States of the Organisation of African, Caribbean and Pacific States (OACPS) differ in many ways – in geography (size, climate); population (size, density, age structure), etc. The Human Development Index shows significant variations among the populations of countries, and also within countries and regions, especially where there is a high level of urbanisation. Agriculture is oriented according to local needs, and conversely, dietary behaviour is oriented according to locally available food, so each country has its traditional value chains. The interactions of all these factors lead to completely different agricultural systems in different countries.

A SmartTech solution for a selected value chain might be successful in a specific region or country, but it cannot always be transferred successfully into a different setting. So listing SmartTech solutions by use-case alone is not sufficient, and additional factors must be considered. This study therefore follows a multi-dimensional approach that takes into account the following contextual factors:

- value chain
- value chain element/step
- agricultural system
- climate zone
- target group
- use-case.

In addition, technical factors include:

- implementer/operator's digital readiness
- target group's digital readiness (literacy level, technological literacy, trust)
- acceptable costs (development, installation, training, continuous operational costs)
- technical environment (electricity supply, mobile coverage, broadband speed)
- potential to integrate into existing processes/systems.

Secondary parameters to consider were:

- language of solution
- locally available support.

There are two alternative approaches for introducing SmartTech into agribusiness processes.

- Re-using existing technologies – applying them in other regions, for other agribusinesses, or for other value chains. Solutions may be downloadable and installable off-of-the-shelf, or may need configuration and/or customisation.
- New development based on existing technologies – this approach is far more complex than deploying an existing solution. Behind a successful IT solution there is often a long and rocky road that has absorbed a lot of resources.

IT development needs expertise and technical resources, and D4Ag solutions particularly need very good insights into the environment where they are intended to work. Not only the agricultural context has to be fully understood, but also the socio-economic and cultural context of the users, their technical literacy and access to technology. Many successful solutions have been built around existing extension and advisory systems, where confidence and trust already exist. The development of a SmartTech solution for agriculture thus needs a high degree of skill in many areas.

Only solutions applicable to ACP horticultural value chains are considered in this report. Generally, an agricultural value chain encompasses the full range of activities, from input-supply, production, harvesting and post-harvest to marketing. In this study, the following horticultural value chain steps are prioritised:

- production
  - soil analysis and advice
  - irrigation solutions
  - plant health and IPM
  - productivity monitoring
- processing
- export and trade
- end customers

and

- traceability – not a value chain step, but connects some or all value chain steps.

This study focuses on SmartTech solutions that originate from ACP Member States, or that have proven successful in ACP horticulture. There are countless precision agriculture solutions available in high-income countries, but they are usually not applicable for low- and middle-income country (LMIC) economies. SmartTech can help to improve efficiency, quality and yields, and thus increase incomes in ACP countries, but the technology needs to be adapted and adopted.

Many of the ICT solutions presented here provide a variety of functionalities (or use-cases), and cannot easily be assigned to a single step in the value chain. This report presents ICT solutions grouped (clustered) for combinations of specific technologies and value chain steps, as shown in the matrix in Table 1.

Table 1 Areas of SmartTech solutions along the horticultural value chain (dark orange, available solutions; light orange, potential for solutions; white, no potential)

	Value chain step							
SmartTech technology	Productivity				Processing	Transport, storage, export, trade	End customers	Traceability
	Soil analysis/ advice	Irrigation	IPM/surveil-lance, plant health	Productivity monitoring				
Agricultural intelligence		Cultivate			IntelloTrack	IntelloTrack GRO Intelli-gence Aibono Seed-to-Plate	Aibono Seed-to-Plate	
AI and ML		Cultivate Fasal	Agrio Agrix Fasal Plantix Xarvio Weather In-sights Zenvus YieldSky					Cropint Foodprint IntelloTrack SourceTrace
Barcodes/QR codes				FarmForce Econet EcoFar-mer	FarmForce			
Big Data			Plantix Xarvio	PlantVillage Nuru UjuziKilimo EcoFarmer				
Blockchain			Skycrafts Aero-space		BreadTrail FoodPrint			SourceTrace BreadTrail

	Value chain step							
SmartTech technology	Productivity				Processing	Transport, storage, export, trade	End customers	Traceability
	Soil analysis/ advice	Irrigation	IPM/surveil-lance, plant health	Productivity monitoring				
GIS			Bayer RMS RapidAim Rentokil TrapView e-FlyWatch Skycrafts Aerospace Aeroview Infield Aibono Seed-to-Plate Astra Aerial Climate Fieldview Skycraft WeFly Agri Zenvus YieldFly	Farmsuite PlantVillage Nuru UjuziKilimo VillageLink				SourceTrace
GPS		Water-Mark	Aeroview Infield Aibono Seed-to-Plate Astra Aerial Climate Fieldview Skycraft Aerospace WeFly Agri Zenvus YieldFly					ChainPoint Cropin SAP Rural Sourcing Management

SmartTech technology	Value chain step: Productivity – Soil analysis/ advice	Productivity – Irrigation	Productivity – IPM/surveil-lance, plant health	Productivity – Productivity monitoring	Processing	Transport, storage, export, trade	End customers	Traceability
IoT		EcoTron Future Pump Sun Culture Teleirrigation Kit WaterHand WaterMark	Bayer RMS PestConnect RapidAim Rentokil SnapTrap TrapView e-FlyWatch			ColdHubs Zenvus Loci Ecozen EcoFrost		SourceTrace
Mobile apps			Xarvio Plantix Zenvus YieldSky	UjuziKilimo Farmsuite				ChainPoint Cropin IntelloTrack SAP Rural Sour-cing Manage-ment SourceTrace
Remote sensing	Sowit Digital Agriculture Platform	Acre Africa	Digital Agriculture Platform Site Pyro	Farmsuite PlantVillage Nuru UjuziKilimo VillageLink				SourceTrace
Sensors and transmission	Ujuzi Kilimo SoilPal Farmshield Aibono Smart Farming ffem soil	SeaBex SunCulture Sinosolar Ferme Digitale FuturePump FarmShield	Xarvio Plantix Zenvus YieldSky HRI Nitrogen App	FarmShield				Cropin

	Value chain step							
SmartTech technology	Productivity				Processing	Transport, storage, export, trade	End customers	Traceability
	Soil analysis/ advice	Irrigation	IPM/surveil-lance, plant health	Productivity monitoring				
Unmanned aerial vehicles (UAVs)/drones	Astra Aerial Climate Fieldview		Aerospace Aeroview Infield Aibono Seed-to-Plate Astra Aerial Climate Fieldview Skycraft WeFly Agri Zenvus YieldFly	WeFly Agri Climate Field-view Zenvus Yield Fly				
Web portals							Aibono Seed-to-Plate	ChainPoint Cropin Foodprint IntelloTrack SAP Rural Sour-cing Manage-ment SourceTrace

3.2 Use-cases

This document focuses on the following SmartTech use-cases:

- Advisory
- Aggregation
- Cooperative management
- Disease control
- Early warning
- Farm management
- Farm surveillance
- Irrigation automation
- Precision farming
- Production monitoring
- Quality control
- Storage
- Supply chain management
- Traceability

The above list excludes IT solutions for food processing, human resources, accounting, insurance, training, information sharing, machine pooling and market access. (E-finance is partly represented as many solutions provide integrated payment functionalities.)
Thus the technologies covered address mainly the following target groups:

- Smallholder/commercial farmers
- Communities/cooperatives
- NGOs/implementers
- Extension services/technicians/village-based agents
- Agrodealers
- Aggregators/off-takers
- Processing industry
- Transport sector

CLUSTER 1

ADVISORY SERVICES: SMS, INTERACTIVE VOICE RESPONSE AND APPS

Technologies	SMS, Interactive voice response (IVR), Apps
Value chain steps	Production
Use-cases	Farm management, Cooperative management, Advisory
Description	Advisory services are delivered by a range of service providers, including mobile network operators (MNOs), agricultural value-added services providers, NGOs and, in some cases, technology vendors, governments and regulatory agencies, often in partnership with MNOs (Figure 7). Basic technology channels for disseminating information still dominate. Given the digital literacy challenges in LMICs, voice is still the most popular delivery channel, followed by SMS.
Examples	Functioning services include InfoTrade Uganda, which is Uganda's Agricultural Market Information Service; Esoko's Digital Farmer Services in Ghana; Dialog's Govi Mithuru in Sri Lanka; Econet's EcoFarmer in Zimbabwe; and iCow in Kenya, Tanzania and Ethiopia. Another service provider that has achieved significant scale is Viamo, a digital communication and behaviour change content provider serving millions of farmers in 17 countries through its Viamo Platform (Viamo provides USSD- and IVR based 3-2-1 services), offered in partnership with several mobile operators.
Implementation and setup	The digitalisation of existing extension services is relatively easy. In most cases, farmers receive information on their simple phones and do not interact directly with the systems. More advanced systems allow farmers to get information on specific topics on demand, but these need either smartphone and internet, IVR or USSD technology. Providing information to smartphone users is the most effective and cheapest approach, and information can easily be localised (GPS geolocation) and customised (by farmer profile). Systems based on USSD or IVR technology are complex and need to involve MNOs and their servers. Unfortunately, smartphone penetration among African smallholders is still low, so pushing messages by SMS and voice messaging is still the most effective way.

Cost	SMS or voice mail messages have continuous costs. There are free bulk SMS services online, but these usually operate from other countries and either do not send to the target country, or are too expensive. So a locally operating bulk SMS service has to be identified, usually provided by a country's MNOs. For smartphone-based solutions, a cloud server is needed and costs arise from development of the solution, or licence costs if a readily available solution is used. Digital advisory services may be sold on a business-to-consumer (B2C) model where the recipient farmer pays for the service; business-to-business (B2B) where agribusinesses pay for the service; or a hybrid. There are also business-to-government (B2G) models, where national or regional governments pay for services on behalf of farmers, such as the NGO Precision Development (PxD) (formerly Precision Agriculture for Development, PAD).
Digital readiness of target users	Most services require only a simple phone to receive messages, and can easily be managed by farmers. Other more complex services need a smartphone. The technology needs to be selected depending on the technological environment of the target group.
Digital readiness of implementing organisation/ business	There is no particular IT level necessary. SMS or voice messaging is usually supported by specific computer programs or web pages. Connecting existing farmer databases with these systems might require some programming or configuration.
Issues to note	Sending information to farmers is simple, but asking information from farmers is complicated. Farmers usually do not invest in SMS to send information. They provide information only if there is no cost to them, and if trust and confidence are already established.

1 KENYA
36 services

including:
Digifarm, Arifu, Wefarm

2 INDIA
34 services

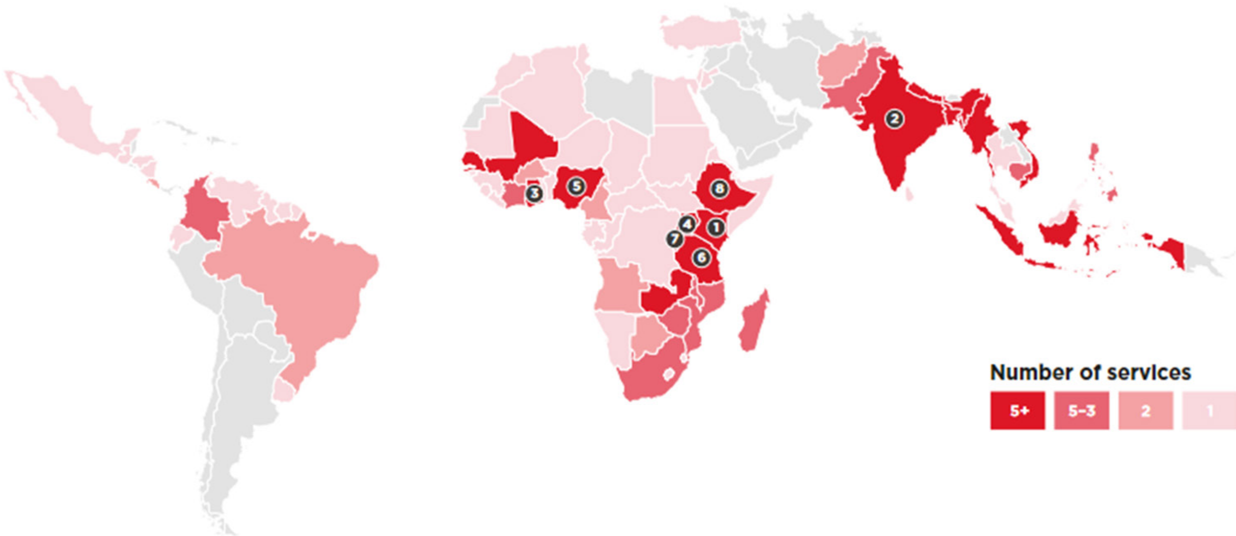
including:
IFFCO Kisan Green SIM, AgroStar, mKRISHI

3 GHANA
21 services

including:
Esoko, Iska, GeoFarmer

4 UGANDA
17 services

including:
Airtel 3-2-1, Wefarm, GeoFarmer



5 NIGERIA
16 services

including:
Airtel 3-2-1, Iska, Zenvus

6 TANZANIA
12 services

including:
Wefarm, Vodacom 3-2-1, Harnessing Agriculture Know How for inputs (HAKIKI)

7 RWANDA
11 services

including:
MTN 3-2-1, Precision Agriculture for Development (PAD), nFrnds mAgri platform

8 ETHIOPIA
11 services

including:
iCow Kalenda, 8028 Farmer Hotline, Precision Agriculture for Development (PAD)

Figure 7 Digital advisory service solutions in LMICs, 2020. Source: GSMA, 2020

CLUSTER 2

REMOTE SENSING: INCREASING PRODUCTION BY IMPROVING ACCESS TO INFORMATION

Technologies	Remote sensing, Sensors, Apps, SMS
Value chain steps	Production
Use-cases	Farm management, Cooperative management, Advisory, Early warning, Precision farming
Description	Lack of data and information hinder farmers' ability to optimise agricultural production. For example, farmers can optimise planting times for crops if they have better knowledge of weather conditions. Access to data and information can significantly improve efficiency of agricultural production, increase yields, and make farmers' livelihoods more sustainable. Remotely sensed data combined with data from ground observations allows us to identify, classify and quantify various parameters important for agricultural production. Researchers combine this data with ground truth data (e.g. soil moisture) to develop various innovative remote sensing applications for agriculture, such as determination of crop water demand, plant health assessment, yield forecast, and alerts for timely predictions of pest infestation or plant stress. But localised and customised information can be sent to farmers only if they have access to GPS-enabled mobile technology, or if their land has been mapped before.

Examples	UjuziKilimo offers timely weather updates and predictive insights through SMS for registered Kenyan customers. UjuziKilimo must have visited and analysed the farm first in order to develop customised information for the farmers. VillageLink Satellite Services in Myanmar is a platform that aggregates satellite data related to agriculture and transforms it into key information. Agribusinesses and organisations can use this information to improve their operations and decision making. A native Android app receives localised weather forecast, crop classification maps and yield estimations, allowing crop performance and crop growth stage tracking, and flood monitoring. The app also connects farmers to agricultural professionals and services. PlantVillage, a user-moderated Q&A forum for agriculture, has developed the Nuru app. Using satellite data from the Food and Agriculture Organization (FAO) WaPOR initiative, this app allows Kenyan farmers to monitor their crops “from eyes in the sky” (Simon, 2019).
Implementation and setup	Satellite data on weather forecasts and gross biomass distribution are more and more freely accessible (e.g. WaPOR). But first the data has to be analysed and processed according to the needs of the users, before sending it to the farmers. Based on application programming interfaces (APIs), this information can be integrated into automatic processes to model crop water demand, biomass distribution, plant health and other parameters. GPS functionality on all smartphones allows this information to be broken down to plot level (provision of localised and customised data) for decision making. However, all these processes demand high-level IT capacities and expertise. Apart from some donor supported systems, there exist hardly solutions that process data and offer tailor made information to the farmers. When setting up such a system, it is important to ensure the information sent to farmers is easy to understand. Short training sessions can help farmers understand the information correctly.
Cost	Free satellite data is available with sufficient precision and resolution for weather information. But this data is not accurate enough for identification of biomass and plant health at smallholder plot level, or for related decision-making. Precise satellite data and data sensed using drones, on the other hand, are very expensive. A good and cost-effective solution cannot always be found. Also, the setup of such systems needs high-performing servers and IT development capacities, and a good internet connection. Once set up, the systems can run automatically.

Digital readiness of target users	Some services, such as weather forecasts sent by SMS, require only a simple phone and can be easily managed by farmers. Other more complex services, such as thematic maps, require a smartphone for reception and user-side skills for interpretation. Offering training to help users understand the information is recommended to increase the efficiency of services.
Digital readiness of implementing organisation/ business	Once completed, the systems automatically process and send the appropriate information to farmers. Adjustments and additional development are required only if data formats or operating systems change.
Issues to note	Only satellite systems that transmit data automatically and repeatedly are suitable. Free systems are operated by FAO (WaPOR, see Cluster 2), the World Meteorological Organization (WMO, 2020), Sentinel Hub (n.d.), and the United Nations (e.g. UNEP/GRID, n.d.), and these data can be accessed through APIs. Computer programs can automatically use this information, analyse data and send it via appropriate channels to farmers. Smartphone technology (GPS) easily allows the visualisation of localised data on maps. However, in many ACP countries only few farmers own smartphones. Translating spatially distributed information into SMS text is more difficult, and spatial variations within a plot cannot be considered.

CLUSTER 3

INTERNET OF THINGS: BETTER FARM MANAGEMENT THROUGH RELIABLE DATA

Technologies	Internet of Things (IoT), Artificial intelligence (AI), Sensors, Drones, Apps, SMS
Value chain steps	Production
Use-cases	Farm management, Supply chain management, Advisory, Precision farming
Description	Work on farms can be optimised if accurate and timely data is available. At some point it becomes impossible or inefficient to manually keep track of all the processes happening on a farm. And effective decision making becomes problematic without a comprehensive database of accurate and timely data. IoT can help to acquire this data automatically using sensors or special machinery, and can help to see the bigger picture, spot potential problems and make appropriate decisions. This technology continuously and automatically gathers information of interest, bridging the gaps in workforce, capacities and availability of measuring devices. IoT devices collect large amounts of data which need sophisticated databases and automated analysis. Machine learning (ML) and Artificial Intelligence (AI) are complementary SmartTech solutions. There are many ways in which IoT can be useful in agriculture. For monitoring, real-time crop control through sensors such as motion and light detectors, soil humidity meters and remote sensing components (drone and satellite images) can help avoid large infestations, optimise watering and fertiliser application schedules, monitor the quality of crops and identify optimal harvest times. In precision farming, tractors collect data on the fields, and later crop health and crop stress are monitored from space, combined with the ground data, and translated into software directives that control nozzles and valves installed on tractors. The tractors then apply the optimal amounts of seed, fertilisers, herbicides, fungicides and pesticides, reducing impact on the environment. IoT is also used in tracking and optimisation in storage, processing and transport. Predictive analysis from all the data collected through sensors and analysed by AI can play a key role in a farm's adaptation to difficult weather conditions such as droughts and floods, which are becoming more and more of an issue as global warming progresses (see e.g. Elsaesser, 2020).

Examples

The Tele-Irrigation Kit of Tech-Innov (Niger) consists of a solar (or wind) station, solar pump, water distribution network and telecom equipment, all remote controlled by phone through an IVR application. The hardware works with data on weather, expected humidity and precipitation, wind strength and solar radiation. This allows farmers to take immediate action based on reliable and objective data, using their mobile phone.

HelloErf (Ethiopia) manages heavy machinery such as tractors and combine harvesters using IoT. The service connects farmers and machinery owners, and allows the latter to plan how they rent their GPS-equipped machinery, organise the most efficient use of time and minimise fuel loss and theft. HelloErf equips the machinery with IoT devices that transmit all the necessary data directly to an app that is accessible by equipment owners as well as farmers. It allows farmers to have access to machinery, and tractor owners to manage their equipment in the most efficient way.

Zenvus Yield (Nigeria) provides farmers with insights on the vegetative health of their crops. Yield is a special hyper-spectral imaging camera that works with the Zenvus web app to provide farmers practical information for their businesses. By analysing the images, stressed crops, droughts, outbreaks of pests and diseases, etc. can be seen and managed. YieldFly uses drones; more affordable for farmers is YieldSky, a camera mounted on a stick to walk around the farm. With Yield and the Smartfarm app working together, farmers can evaluate the effectiveness of irrigation and fertiliser application by correlating soil data with overall vegetative crop health.

Implementation and setup

Installation and management of IoT technology requires resources: it can be expensive, and farmers need to be tech-savvy to operate it. Depending on the level of complexity, it might require farmers to have a smartphone in order to use a mobile app, or a simple phone to receive SMS or voice messages. There are some examples where solar-powered IoT comes readily installed on pumps or soil sensors, which communicate with servers through GSM or other transmission technologies. This does not require any special training for farmers, but a local service provider is needed for maintenance.

The combination of different sources of data (sensors, soil meters, GPS trackers, etc.) implies a complex analysis system that produces meaningful predictions and trends, customised to the needs of the customers. The final product, the basis for decision making, not only needs to be accessible for farmers without special IT expertise, but also easily comprehensible and ready for real-life farm management decisions.

Cost	Implementation of IoT technologies is very costly, especially in the initial stages. Installation of the physical hardware, whether an irrigation system, soil monitoring or tractor management, requires services of trained professionals and a significant amount of expensive equipment. It is likely that in most cases, smallholders would not be able to bear the entire cost on their own. However, there are cases where the costs of IoT technology are integrated into suitable business models that are affordable for farmers. In some cases, the data collected by the devices no longer belongs to the farmer but is used by third parties for different purposes. Alternatively, the cost of implementation may be split among a community of farmers if it can potentially benefit the whole area.
Digital readiness of target users	Depending on the complexity of the service, it might require as little as a simple phone with the ability to receive SMS; or as much as operating a drone and using complex analytical tools. Most solutions transmit the information collected from devices through a mobile app directly to a farmer's smartphone. Use of such technology relies on access to regular internet connection, otherwise the real-time nature of the data cannot be guaranteed.
Digital readiness of implementing organisation/ business	Initial stages require significant installation efforts. Once the hardware is installed, maintenance, data analysis and use of appropriate AI technology become the focus.
Issues to note	Many of the solutions available rely heavily on stable internet access and on farmers' ability to use a smartphone. Farmers do not necessarily need to understand the technology, but they do need to understand the information products to derive appropriate decisions.

CLUSTER 4

INTERNET OF THINGS: TRANSPORTATION AND STORAGE

Technologies	IoT, AI, Sensors, Drones, Apps, SMS
Value chain steps	Transport, storage
Use-cases	Farm management, Supply chain management, Storage
Description	Transportation and storage are two value chain steps that can be improved significantly using IoT. Smart tags, GPS-equipped trackers and QR scanning devices can help achieve complete transparency and contribute to the goal of traceability. Transport and storage in ACP countries faces various challenges. In particular, the cooling of products is essential and can significantly help to reduce losses. As many countries still face the problem of hunger, reducing food waste is a necessity. IoT technology has been adapted to solve that issue, particularly through solutions such as smart cool rooms (stationary or transportable), smart GPS tracker tags, and humidity, temperature and defrosting cycle sensors.

Examples

ColdHubs is a Nigerian company that addresses the problem of post-harvest losses in fruit, vegetables and other perishable foods. ColdHubs provides "plug-and-play" modular, solar-powered walk-in cold rooms for 24/7 off-grid storage and preservation of perishable foods. ColdHubs facilities are installed in major food production and consumption centres (in markets and on farms). Farmers place their produce in clean plastic crates which are stacked inside the cold room, extending the freshness of fruit, vegetables and other perishable food from 2 days to about 21 days. Energy from solar panels mounted on the roof-top of the cold room is stored in high-capacity batteries. By saving 42,024 tons of food from spoilage in 2020, the cold rooms increased customers' income by an average of US$50 (Swiss Re Foundation, 2020).

Zenvus Loci (Nigeria) is a largely disposable package tracker, engineered to be re-usable. It easily tracks and monitors packages, shipments and mobile assets in near-real time, outdoors, indoors, inside packages and inside vehicles.

EcoFrost from Indian company Ecozen is a system consisting of a solar-powered cold storage room for fresh perishable produce and a mobile app. Through IoT, real-time data from the Ecofrost storage room is captured to help with monitoring and provide predictive maintenance. EcozenAI, the program behind all the Ecozen solutions, conducts predictive diagnostics using AI and data science. All the analytics are available through a mobile or a web app.

Implementation and setup	Initial setup of solutions such as smart cold rooms require professional expertise as well as a significant effort in terms of delivery and logistics. Solar panels, batteries and inverters need to be installed under the supervision of a professional. However, once the cold storage room is installed, maintenance efforts will be minimal, depending on the weather conditions, type of energy source, and how heavily the equipment is used. Tracking technology does not require complicated installation procedures, but might call for training among operators. Correct monitoring, and immediate and appropriate actions in case of problems, might be challenging without prior training and experience with the technology. Depending on the level of sophistication, some technologies will require constant (or at least occasional) access to a network, while others can operate autonomously. Certain cold storage/transportation rooms transmit data to servers through Global System for Mobile Communications (GSM) or other transmission technologies. GPS technology used for tracking does not require any special training or additional effort from farmers, and is generally accessible. All data collected from smart sensors and devices can be analysed with the help of ML and AI, and predictive models can be built. The data and analytics, plus recommendations, can be transmitted to the user via mobile and web apps.
Cost	Complex IoT technology might not be accessible to smallholder farmers, but larger farms and off-takers can increase their profits significantly by improving traceability and reducing waste of perishable foods, which makes such IoT solutions an attractive investment. Installation and maintenance of solar panels and cold storage spaces is financially challenging and requires training effort from the user; however, an entire community or the whole supply value chain can benefit greatly by saving valuable resources and creating a more sustainable market for farmers' produce. Given the reduction of losses, functioning business models can be developed. Data collected from both tracking and cooling equipment is of interest not only to farmers and distributors, but also to large corporations trying to analyse markets, and research teams studying agriculture in the region. This can make the operationalisation of such technology mutually beneficial, and distribute the cost.

Digital readiness of target users	The solutions do not require any technical capacities from the farmer. They do, however, require farmers to comply with the rules of storage and to provide only clean produce which does not harm other customers' products. The introduction of cooling technology is easy for agricultural producers to understand, and the positive results are quickly visible. Tracking devices are not generally used on farms, and only technicians of off-takers and in the transport sector have to deal with this technology.
Digital readiness of implementing organisation/ business	Setup and maintenance of storage units, refrigerators and solar panels requires the services of trained professionals. Data analysis and prediction implies use of AI and ML. These two factors, together with the fact that some solutions operate sensors and humidity meters, mean that a sizeable effort and high level of technology will be needed to provide such technology.
Issues to note	The provision of cooling services needs to be underpinned by a promotion campaign. As soon as farmers see the reduced losses and increased incomes, they are willing to pay for the service.

CLUSTER 5

DIGITAL SUPPLY CHAIN MANAGEMENT AND TRACEABILITY

Technologies	Mobile app, Web app, SMS, GPS, barcodes/QR codes, digital scales
Value chain steps	Traceability (from harvest to consumer; may include input delivery)
Use-cases	Supply chain management, Aggregation, Quality control
Description	End users of international markets want to be fully informed about where food comes from. Lack of traceability of agricultural products prevents farmers from entering these markets. Traceability is also key to certification. A digitised value chain traces products and activities, and can benefit all stakeholders by creating greater transparency about the source of food, while helping primary producers to access much-needed resources including finance, inputs and fair prices. Software solutions for supply chain management offer tools to help manage and sell crops, buy and track goods, and trace products back to the farms where they were made. In case of product quality issues, they help to identify the origin of the problem. Most ICT solutions in agriculture were conceptualised for a specific agro-industrial subsector and a specific situation. In reality, different agribusinesses vary in their crops or products, their size, country, language, environmental conditions, and remoteness of location. In horticulture, different supply chains rely on different sourcing systems, and on different procedures for quality control, processing and packaging, so supply chain management solutions are usually very case-specific. It is difficult to find ready-to-use software for a given setting, and it is usually necessary to make adaptions and reconfigurations. In some cases, only the development of new software can fully map the processes. These tools aim to enable agribusinesses to have full visibility of the agricultural last mile, maintain a digital record of suppliers, and facilitate auditing processes for certification requirements. They frequently also integrate communication tools, e-payment services and other important functionalities and services. Elsaesser (2017) lists 10 effective ICT tools to enhance the competitiveness of contract farming. Smallholders can benefit from the information collected, for example by being provided with annual reports on inputs, production and revenues. This will help them to develop management capacities, helping to building trust and confidence between smallholders and buyers/lead farms.

Examples

eProd Solutions, one of the rare companies present in East and West Africa (and Haiti), started by developing software for its own contract farming business which exports bird's-eye chillies to Europe. Today they offer IT solutions for various value chains including dairy and livestock. This off-the-shelf product can be used flexibly through configuration. It is used by 75 clients serving over 250,000 farmers in 22 different agricultural sectors, in 10 languages and in 12 countries.

Connected Farmer, a management solution by Mezzanine (a Vodafone-owned company), allows agribusinesses to digitise operations with farmers' registration, input provision management, communication and payment via mobile money. The solution has a track-and-trace component, improving visibility of last-mile operations.

Aibono is India's first AI-powered fresh food aggregator. Aibono is an end-to-end agritech platform specialising in aggregation and direct supply of fresh fruit and vegetables directly to the doorstep. SAP Rural Sourcing Management is a solution for building a sustainable and traceable agriculture supply chain. Designed for agribusiness companies and powered by the SAP Business Technology Platform, this supply chain management software connects smallholder farmers to the agricultural value chain.

Implementation and setup

Supply chain management is a complex business, so it is demanding to find an appropriate ICT solution. Most available software needs modification and configuration to adopt it to the given situation. eProd, for instance, claims to need five days' consultancy to be fully operational for the client. Commercial software solutions from Europe and overseas are only suitable if a local consulting service is provided.

The development of an appropriate solution by a competent local IT service provider can also be a suitable and sustainable solution as continuous licence costs are avoided. A welcome synergy effect is created by the development and strengthening of local IT service providers.

Mobile technology needs web servers – which are expensive and difficult to manage – so it is recommended to make use of cloud-based services. Care should be taken with tools that require constant internet access. Through the introduction of barcodes on farmer ID cards, tickets and stickers, data entry can be almost completely automated, reducing time and improving data quality.

Cost	Stepping into digital supply chain management needs the setup of a competent IT department at company level, and all system users need appropriate training. This entails permanent costs, and it must be evaluated whether the added value is worth the effort. Introducing supply management software also usually requires additional hardware, such as (robust) mobile devices, barcode printers, handheld scanners and digital scales. Mobile devices should be rugged and water-resistant and, where possible, alternatively operable on battery. A budget should be reserved for consumables such as ID cards, product stickers and toner. The software itself must either be specially developed (preferably by a competent local IT service provider), or a commercial software product must be adapted and configured to the needs by a consultant of the IT company. The commercial solutions follow various business models and entail licence costs.
Digital readiness of target users	Smallholders do not need to operate any IT system themselves. The users who operate the system (collectors, technicians, extensionists) need an appropriate level of computer literacy. Decision makers at management level will access the data as tables, charts, reports and maps, and need the relevant analytical skills.
Digital readiness of implementing organisation/ business	The operation of supply chain management and traceability software requires IT staff, not always easy to find in remote areas. For an agribusiness in need of supply chain management software, the selected solutions should be kept as simple as possible.
Issues to note	It is possible to set up functioning traceability and supply chain management systems without any higher information technology in the field. Tickets and stickers can be printed at central level and delivered to extensionists, field agents, lead farmers, etc., who then apply them correctly. At central level, barcode scanners can then automate processes and integrate all information correctly. Keys to success include considering the local setting (idioms, network availability, dust and water, grid); using cloud-based services; and partnering with local IT firms. Using farmer ID cards (with scannable codes where possible) reduces workload and improves data quality; assigning unique alphanumeric codes to farmers avoids duplication; barcodes are preferable (QR codes are more vulnerable to dust and mechanical problems). Mobile technologies should have offline capability, and it is important to maintain a paper-based backup system.

CLUSTER 6

ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING FOR PLANT HEALTH AND CROP MANAGEMENT

Technologies	AI, ML, Satellites, Sensors, Apps
Value chain steps	Production
Use-cases	Farm management, Advisory, Early warning, Precision farming
Description	Some agricultural value chain steps have particularly high potential AI and ML technologies. Pest control, plant health and crop management are fields where AI can help improve the lives of farmers across the world, helping to prevent the spread of diseases and maximising harvesting, while also collecting a wide range of data. Comprehensive AI-based analysis of this data allows creation and adjustment of predictive models, automation of advice and insights for farmers, and optimisation of irrigation and fertiliser application schedules. With the help of these technologies, farmers get access to services such as pest and disease modelling, optimal planting time, fertiliser timing recommendations, product suitability and site similarity, environmental trend analysis, early famine warning, irrigation management, etc.

Examples

Fasal (India) monitors critical parameters on a farm and uploads data to the Fasal cloud platform. AI-based analysis of the data makes the crop's health status accessible to the user anytime, anywhere, on any device for data-driven decision making. Fasal's prediction engine models ideal growth conditions, resource requirements (including irrigation, sprays, fertiliser application), and preventive measures. Fasal provides a farm-specific, micro-climatic, 14-day forecast. Its disease prediction and assessment systems forewarn farmers and agri-institutions about the possibility of a crop disease and its severity, or the possibility of pest outbreaks so that farmers can precisely plan their actions.

Agrio is a pest and disease alert system with tools for identification and recommendations. It has management tools for inspectors, and targets field inspectors rather than farmers. The AI algorithms detect vegetation issues to allow farmers to know precisely when and where to act. A hyperlocal weather forecast completes the services. While the app for pest and disease detection is free for smartphone users, and hyper-localised weather forecasting is provided for free, additional functionalities including a satellite-monitoring web app, and disease and pest alerts, cost monthly subscription fees.

aWhere's Weather Insights is designed to drive crop and spatial models. The sensed data is integrated with other spatial data to generate insights on how weather variability impacts society. Insight products draw on years of practical expertise in agrometeorology, agronomy, crop improvement, markets and policies to empower clients to make relevant, timely and quantitative decisions to enhance production and product quality, and reduce risks. Based on real-time data, AI and ML algorithms generate the necessary decisions for pest and disease control, planting and irrigation.

Plantix is a free Android app that provides information and personalised advice on plant health. Farmers use Plantix as a portable diagnostic tool for fruit, vegetables and other crops. They take images of their plants, and an AI system on the server analyses the uploaded images and provides an instant diagnosis of the vegetation pathology and information on treatment. The Plantix community, made up of international experts and other players in the sector, provides access to valuable advice applicable at regional level. The database is constantly improved with added images and user comments.

Zenvus Yield (Nigeria) provides farmers with insights on the vegetative health of their crops. Yield is a special hyper-spectral imaging camera that works with the Zenvus web app to provide farmers practical information for their businesses. By analysing the images, stressed crops, droughts, outbreaks of pests and diseases, etc. can be seen and managed. YieldFly uses drones; more affordable for farmers is YieldSky, a camera mounted on a stick to walk around the farm.

Examples (bis)

PlantVillage, a user-moderated Q&A forum for agriculture, has developed the Nuru app. Using satellite data from the Food and Agriculture Organization (FAO) WaPOR initiative, this app allows Kenyan farmers to monitor their crops "from eyes in the sky" (Simon, 2019).

Xarvio offers digital farming solutions including: xarvio® SCOUTING (photo-based pheromone trap analysis); xarvio® FIELD MANAGER (digital solution for field monitor, seeding optimisation, nutrient management, and crop protection and growth regulator management); and xarvio® HEALTHY FIELDS (provides a season- and field-specific optimised crop protection strategy and ensures the required dosage at the optimised timing). These digital products are based on a crop modelling platform, which delivers independent, field-zone-specific agronomic advice that enables farmers to produce their crops most efficiently and sustainably.

Agrix Tech offers AI-based pest and disease diagnosis for plants in African languages, and can be operated offline.

Implementation and setup	AI- and ML-based services are becoming more and more accessible, even to smallholder farmers. The implementation of AI and ML algorithms for agricultural purposes is complex and requires a team of data scientists and specialists in agriculture to work together. Farmers access the data through smartphones, web applications or even SMS. The collection of the necessary data requires special equipment, such as sensors, smart irrigation systems, drones or satellite images of high resolution and frequency. Parts of the analysis can be based on satellite imagery without any additional efforts or hardware. Some of the solutions are downloadable and ready-to-use, the user only needs a smartphone with camera and GPS. From the standpoint of the user, it is important that recommendations and advice are delivered in a timely and understandable manner. Even farmers who do have a smartphone might not necessarily be familiar with complex terminology, and might need clear and accessible instructions.
Cost	The cost of implementing AI and ML solutions depends greatly on what kind of technology is used to collect the data. For apps that determine the health of the crop by analysing a photo or a free satellite image, the cost, as well as setup efforts, will not be overwhelming. Plantix, for instance, can be used for free, only a smartphone and some user training is needed. But AI solutions that rely on data from sophisticated sensors and/or drone imagery might be very costly. The development of a new AI/ML-based solution can be expected to be the most demanding in terms of resources and investment. However, once the programs are running and the ML algorithms are in place, there is only a need to check the system for bugs and provide customer support.
Digital readiness of target users	Farmers wanting to use the benefits of AI technology will probably need access to a smartphone with internet access, camera and GPS, or a computer. They can benefit from the services without understanding the procedures. A short introduction to the main functions and solution options might be necessary.
Digital readiness of implementing organisation/ business	AI is a complicated technology that requires serious proficiency in data science as well as profound knowledge of program development. A company that wants to develop AI/ML technologies is likely to need a team of highly skilled professionals.
Issues to note	Artificial intelligence is a relatively new field and its application in digital agriculture is not yet very common. Many products that are marketed with the label "AI" are in reality only based on high-performance databases. Africa's first AI Research Centre in Brazzaville, Congo, launched by the UN Economic Commission for Africa (ECA, 2022), focuses on this technology and could become a game-changer.

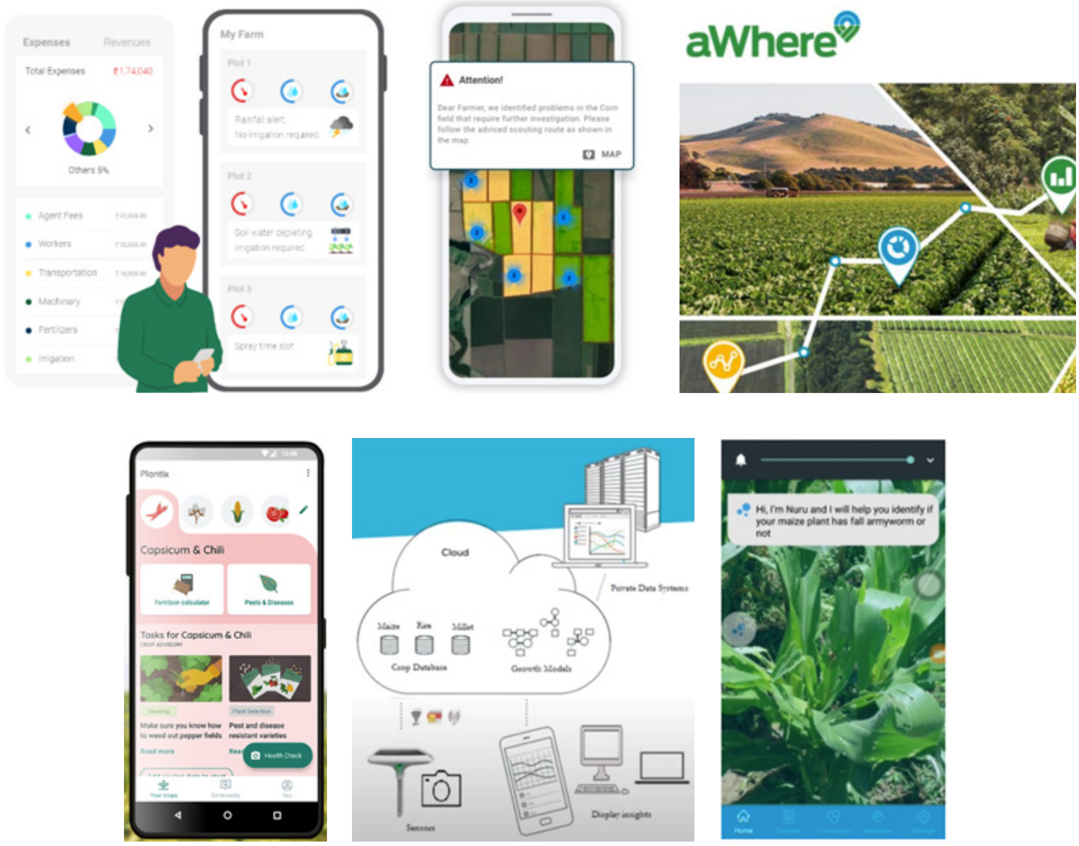


Figure 8 The featured apps: left to right, Fasal; AGRIO, aWhere, Plantix, Zenvus, Nuru

CLUSTER 7

SENSORS FOR SURVEILLANCE OF SOIL AND WATER PARAMETERS

Technologies	Sensors, Apps
Value chain steps	Production
Use-cases	Farm management, Advisory, Early warning, Precision farming
Description	Current smartphones are literally "stuffed" with sensors. These include ambient light, proximity, acceleration and rotation sensors (gyroscope), electromagnetic sensor, digital compass (magnetometer), fingerprint scanner, and sensors for determining location (GPS). Aside from GPS, most of these sensors have little applicability in agriculture. However, it is possible to upgrade smartphones with external sensors, which can also be connected with other devices (such as microcomputers) to control systems such as automatic irrigation and even fertiliser application. These sensors need to transmit the measured signals (by cable, WiFi, Bluetooth, LoRaWan or GPRS) to a control unit that stores the signals. A control unit can receive data from one or many sensors. Specific software then translates the data into directives for the user, or automatically controls devices such as nozzles and sprayers. Soil moisture sensors can achieve optimal water application; humidity and temperature sensors can control ventilation and cooling in greenhouses; and infrared sensors can measure plant stress.

Examples	The Horticultural Research Institute has developed a Smartphone Nitrogen App which can detect the nitrogen status of crops. The Smart N Sensor is based on two cameras that take pictures of plants in red and near-infrared bandwidth. Similarly to the NDVI, the difference between the two signals is proportional to the plant stress (Adhikari and Nemali, 2020). In India, the Foundation for Environmental Monitoring (ffem) and GIZ have developed the smartphone-based ffem soil for spectrographic soil testing (NPK). The app can be downloaded from Google Play Store, and is cheaper and more accurate than conventional soil tests. After preparing a soil sample, the test sample is set on the smartphone camera which then can assess pH, nitrogen, phosphorus, potassium, organic carbon, boron, available iron, sulfur and zinc (Green Innovation Centre India, 2020). Another ffem app allows the assessment of water quality. UjuziKlimo processes millions of data points each day with Soil Pal to create a complete soil and agronomic data pool that is both field specific and highly accurate.
Implementation and setup	The readily available sensor technology is simple to use. Instructions and manuals are available and can be used for trainers to prepare. Apps usually support interpretation of the results and deliver relevant advice. But the development of such solutions needs deep research, and usually is done by universities and research institutes.
Cost	Making use of this technology might need sensors, software and testing equipment. Costs may be low or high depending on the solution. Use of the ffem testing app is free, and even the app source code can be freely accessed (open source).
Digital readiness of target users	Usually extensionists, technicians, village-based advisors or lead farmers carry out the testing; however, farmers can be trained to operate the systems themselves.
Digital readiness of implementing organisation/ business	Applying the available solutions does not need much preparation. But the development of new sensors and testing apps is complex and usually needs cooperation with research institutes.
Issues to note	Data collection is at the basis of any ML and AI system. Automatic collection is preferred but not always possible. Soil sampling, for instance, needs manual sampling.

CLUSTER 8

SMART TRAPS FOR INTEGRATED PEST MANAGEMENT

Technologies	Sensors, Apps
Value chain steps	Production
Use-cases	Farm management, Advisory, Early warning, Precision farming
Description	Pest monitoring and identification are critical steps in a successful integrated pest management (IPM) programme. Traditionally, pest monitoring has been a labour-intensive process with daily or weekly inspections and manual entry of population data into spreadsheets.
Examples	The Alabama Cooperative Extension System (Alabama A&M and Auburn University, USA) carries out research on modern solutions using automatic traps for pest surveillance. They developed the DTN Smart Traps: adhesive traps with a top-mounted camera that automatically sends counts and images to DTN software. The photo quality of the Smart Traps is excellent, as is the accurate counting of different moth species. Photos allow easy verification of totals in a trapping period. The DTN software is a very useful interface for archiving trap data from multiple sites. The automatic traps reliably show changes in pest activity over a long season. Bayer has developed Digital Pest Management, IoT-equipped rodent traps that provide 24/7 monitoring and real-time capture alerts, allowing proactive responses instead of relying on manual trap checking. The system sends real-time automated alerts to smartphones across multiple facilities. An Android app visualises the facilities and helps to localise the problem. SnapTrap, an Australian innovation, is a trapping system that has been developed and trialled on-farm. It is a digital camera system mounted on the standard fruit fly traps (Lynnfield traps) used by state governments for pest monitoring. The trap records a high-resolution photo every few hours during daylight and uploads them to the cloud, where they can be reviewed. Access to the images is via a secure website and can be done on any internet-connected device such as a laptop or mobile phone. Alongside trap contents, SnapTrap also records temperature logs and information from other environmental sensors so that the system can provide degree-day calculations for life-cycle predictions, which can assist with improved timing of fruit fly control activities. SnapTrap is solar powered and connects through the mobile phone network, so it can be installed almost anywhere that gets sunlight.

It has been successfully used even in very low mobile signal locations. It can also use WiFi where available.

RapidAIM (CSIRO) provides hi-tech traps with special casings. Using a smartphone or tablet, users can assess fruit fly pressure and hot spots, receive real-time alerts, view historical trends, log spray records, and see where control is working. However, the traps have a high annual cost, and provide a localised pest forecast only for Australian destinations. Such systems need a large amount of accurate and up-to-date data which is difficult to collect, and thus not simple to scale up or scale out to a new region.

Examples (bis)

Trapview is another professional solution. Based on Trapview technology, ADAMA Australia has built a nationwide network of over 500 automated pest traps targeting key Australian insect pests. The network provides a clear understanding of pest pressure within a growing region, and supports decision makers to improve timing of insecticide applications.

PestConnect by Rentokil offers similar functionalities: IoT-based smart traps and an Android app with dashboard for statistics and maps. These solutions are for sheds and storage buildings rather than for outdoors.

The EU-funded E-FLYWATCH project has developed an innovative way to identify fruit flies by their wing frequency. The trap is a unique, fully autonomous insect trap with integrated electronics and communication modules able to capture real-time images of Mediterranean fruit flies and olive fruit flies entering the traps, and to transmit the images and other information including location and environmental data. The E-FLYWATCH trap links to a centralised data collection service providing real-time warnings to end users and historical analysis of infested areas via an app.

The Bayer Rodent Monitoring System (RMS) is a wireless network of high-tech sensors in traps that monitor and broadcast their status through radio signals. Cloud software can send real-time notifications to users whenever a rodent is caught, or record counts of bait station activity.

Implementation and setup

Smart traps are still under research, and the professional solutions that exist are mainly for industrialised regions. Most smart traps are based on the familiar sticky traps or pheromone traps, but add a combination of cameras or other sensors to provide up-to-date information about what is happening in an orchard or field, and what pests are present. Like an automated weather station, smart traps can greatly reduce the need to visit trap sites in person, as they send information directly to a server.

Cost	Making use of this technology might need sensors, software and modified traps. There are no monitoring systems readily available to install that are suitable for the usual horticultural pests in ACP regions, but it is an interesting field for research and worth exploring. Continuous costs arise from permanent monitoring and maintenance of the traps, and the transmission technology. To reduce data transmission costs, LoRaWan technology can be used (where available); or stations can collect and bundle data from many traps using WiFi before uploading.
Digital readiness of target users	As the system is usually based on standard traps equipped with IoT, there is a need for regular control, maintenance and battery exchange.
Digital readiness of implementing organisation/ business	Usually it is not farmers who are operating high-end trap devices. Government or regional organisations, cooperatives and NGOs have the capacity to operate networks of these devices. However, farmers need to conduct monitoring on their fields, and digital IPM solutions can report the observations to a central analysis centre.
Issues to note	A highly interesting field for research with a high potential for SmartTech. Currently available professional solutions are for industrialised countries.

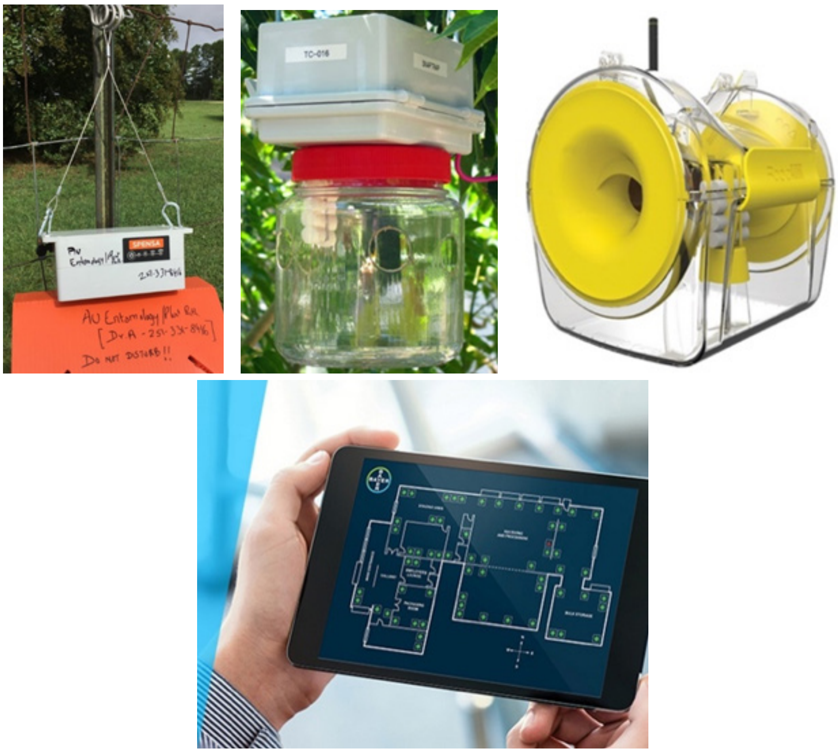


Figure 9 Examples of smart traps: left to right, DTN Smart Trap, Snap Trap, RapidAIM's smart trap, Bayer's RMS

CLUSTER 9

DRONES FOR PEST/DISEASE CONTROL AND PLANT HEALTH SURVEILLANCE

Technologies	Drones, Sensors, Remote sensing, GPS, GIS
Value chain steps	Production
Use-cases	Disease control
Description	Areas of crop or forestry can be surveyed within hours or minutes using drones, which otherwise would take days of work on the ground. This makes it possible to monitor vast fields of crops on a regular basis. Drones can fly autonomously; repetitive flights can be programmed and changes are detected by automatic analysis of the pictures. Standard drones can carry lightweight equipment such as cameras and sensors. Larger drones can even carry tanks and nozzles for spraying. Remote sensing techniques allow the detection of plants under stress. Different crop indices such as NDVI and RVI can help to detect pest and disease or water stress from space. LIDAR sensors can help to produce precise digital elevation models.
Examples	The Aeroview InField App by Aerobotics, Aibono Seed-To-Plate (India), Astral Aerial (Kenya), WeFly Agri (Côte d'Ivoire) and ThirdEye Systems (Israel) all are locally operating drone service providers offering mapping of crop health. Plant health detection is done via NDVI and the final products are maps showing crop health parameters. Skykrafts Aerospace (India) has developed Kisan Drone, the world's smallest spraying drone, but the small cargo load limits applicability.
Implementation and setup	Remote sensing-based workflows for biomass detection and plant health surveillance are sufficiently developed, and compatible commercial remote-sensing software exists for every drone type. There are first drones on the market that offer real-time, on-the-fly biomass assessment, without the usual post-processing of images. But sufficient expertise is needed to operate the drones and to interpret the data.
Cost	The technology is expensive and small farms cannot afford it. But service providers can offer these high-tech services to larger farms or cooperatives.

Digital readiness of target users	Usually, drone products are delivered as maps that need interpretation, and appropriate skills are necessary. Some solutions provide drone-based decisions to smartphones in the form of easily understandable directives that can be localised and custom-tailored as the smartphone delivers its coordinates to the server. These solutions claim to bridge the "last mile", but in reality most farmers do not have smartphones and there is still a distance to bridge between the person with the smartphone (extensionist, technician) and the farmer.
Digital readiness of implementing organisation/ business	Operating a drone service needs technical expertise as well as the necessary flight authorisations, which are not always and everywhere easy to get. The processing of images needs software, expertise and time. Consequently, drones are usually operated by highly specialised service providers.
Issues to note	In many ACP countries there is no drone regulation, which is tantamount to a drone ban. In other countries it is theoretically possible to get drone flights approved, but only after contacting up to six different ministries. In countries with drone regulation, there is usually a market of drone service providers with the necessary capacities to provide products for agriculture. If they do exist, local drone service providers should be preferred as import and taxation of drone material can be difficult.

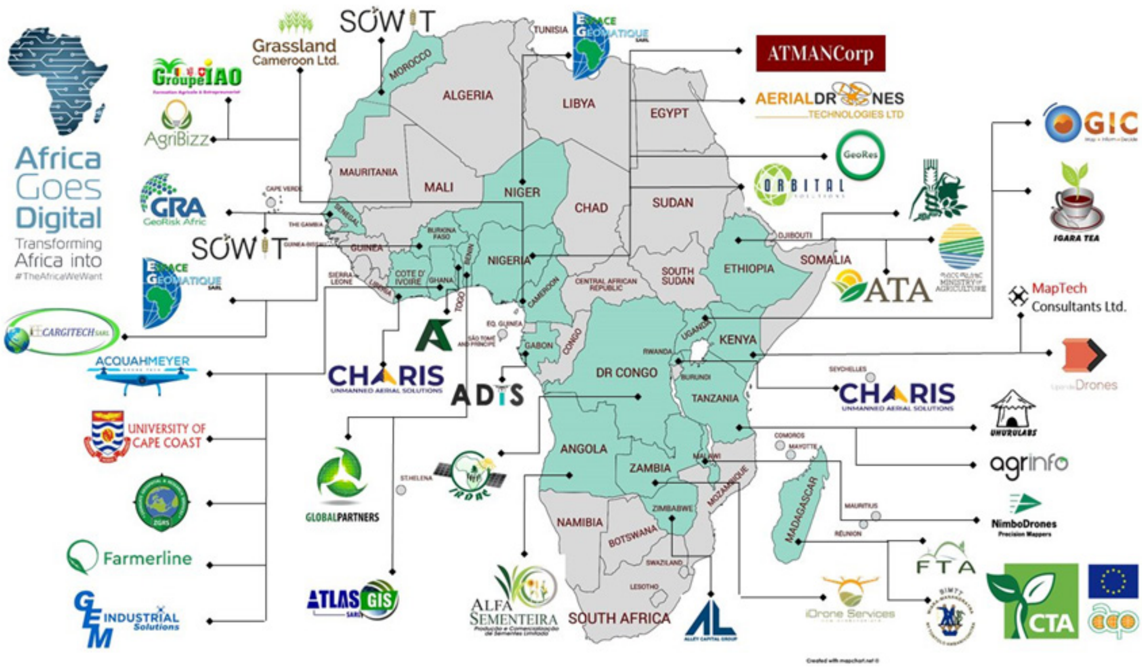


Figure 10 Main drone service providers in Africa. Source: Africa Goes Digital (2022)

CLUSTER 10

DRONES FOR MAPPING AREAS AND CROP PRODUCTIVITY

Technologies	Drones, Sensors, Remote sensing
Value chain steps	Production
Use-cases	Production monitoring, Farm surveillance
Description	Not all smallholder farmers in ACP countries have a clear picture of the size of the land they farm. While there are smartphone apps that can measure land by circling the plots, not all farmland is easily accessible. By use of drones, plots can be measured exactly, and by use of drone-based near infrared (NIR) cameras, biomass can be calculated and productivity monitored. In areas of irrigation agriculture, NIR technology can help estimating water consumption and identifying illicit water abstraction.
Examples	The Aeroview InField App by Aerobotics, Aibono Seed-To-Plate (India), Astral Aerial (Kenya), WeFly Agri (Côte d'Ivoire) and ThirdEye Systems (Israel) all are locally operating drone service providers offering mapping solutions. The remotely sensed data then can be overlaid on satellite images using GIS systems for further processing.
Implementation and setup	Most drone types come with commercial remote-sensing software which allows mapping from the sky. But sufficient expertise is necessary for operating the drones and processing the images. GIS expertise is always needed in order to overlay, convert and classify the drone data.
Cost	The technology is expensive and small farms cannot afford it. But service providers can offer these high-tech services to larger farms or cooperatives.
Digital readiness of target users	The target group for this type of product is not farmers. While farmers might be interested in the exact acreage of their plots, biomass maps and water abstraction maps are of more interest to decision makers, unless data interpretation services are provided and information is transformed into actionable insights. Drone technology is expensive, so the target groups are larger farms, researchers and government institutions.
Digital readiness of implementing organisation/ business	To operate a drone service needs technical expertise; the processing of images especially needs resources in terms of software, remote sensing capacities and time. So drones are usually operated by highly specialised service providers.

Issues to note	In many ACP countries there is no drone regulation, which is tantamount to a drone ban. In other countries it is theoretically possible to get drone flights approved, but only after contacting up to six different ministries. In countries with drone regulation, there is usually a market of drone service providers with the necessary capacities to provide products for agriculture. If they do exist, local drone service providers should be preferred as import and taxation of drone material can be difficult.

CLUSTER 11

MONITORING SENSORS, MICROCOMPUTERS AND DATA TRANSMISSION FOR AUTOMATED IRRIGATION

Technologies	Sensors, transmission, automation
Value chain steps	Production
Use-cases	Irrigation automation
Description	The availability and affordability of sensors and transmission technologies nowadays allow dense measuring networks. Remotely controllable devices allow the setup of automated irrigation, which not only saves water and energy, but also helps to deliver the best water volumes to the plant so that the highest yields are achieved. A wide range of technologies are available to measure all sorts of physical parameters, including meteorological and soil data and water availability. Water quality and plant health can also be assessed by sensors in the field or remotely using drones and satellites. Various transmission technologies are available to send the data to the cloud for centralised analysis, or to a local microcomputer. Devices such as solar pumps, weirs and valves are remotely controlled to automate irrigation and optimise water use, energy consumption and yields. The use of sensor-equipped solar pumps helps to measure water consumption, reducing emissions and saving energy. Automation targets the highest yields with the lowest water, energy and labour costs.

Chameleon sensors developed by CSIRO offer an inexpensive, easy-to-use and effective system to monitor soil water levels. The sensors provide farmers with an easily understood readout. The system has been designed to be inexpensively manufactured, simple to install and easy to understand. An additional suite of tools allows measurement of salt and nitrate levels. Through improved water-use efficiency and the reduction of diseases previously promoted by over-watering, farmers have seen up to 30% increases in crop yields, as well as reductions in water use by as much as 30% (CSIRO, n.d.).

Examples

Simusolar (Tanzania) offers clean energy solutions for agribusiness, and supports remote control and monitoring to ensure security and services beyond the grid and beyond the network. Simusolar offers a pay-as-you-go system that enables smallholders to afford the technology, and they can pay by phone.

SunCulture (Kenya) combines solar pumping technology with an IoT platform and ML algorithms, which enable systems to predict trends and optimise performance in real time. They also provide a pay-as-you-go model which is cheaper than paying for generator fuel.

In India, FreeDesign calibrates cheap Watermark sensors with the help of professional Delta-T sensors to provide farmers with affordable yet accurate soil moisture sensor technology.

FarmShield™ from Synnefa in Kenya enables remote control of farms from mobile phones and dashboards based on real-time information on fertiliser application and irrigation needs for the crop. Grid sensors measure different parameters and send the data to the cloud, where it is analysed. Real-time alerts and advice are fed back to farmers via SMS, email or app alerts.

Examples (bis)

Tech-Innov is a social enterprise in Niger that develops and markets the Ferme Digitale Ecologique (Digital Ecological Farm) with its Télé-Irrigation and related systems, including intelligent bio-fertiliser, automatic watering, rural drinking water kiosk, mobile weather and video surveillance in remote areas. All these innovations are based on sensors and solar energy, and can be monitored and controlled through apps.

Seabex is an e-monitoring and smart automation system from Tunisia that helps farmers find the right balance of water consumption needed for better quality and quantity production. Seabex monitors and controls in real time the key environmental parameters of a farm, and interacts and reacts autonomously to variations in environmental parameters.

Implementation and setup	Many actors are developing systems for automatic irrigation, and many systems are available at different technology levels. In arid and semi-arid countries there are generally a number of competent consulting firms available with knowledge in the field. It is recommended to partner with local firms not only to save costs, but also to build and strengthen local capacities.
Cost	Whether systems use remotely sensed data or data from locally installed sensors, the related costs are high. However, sensors are becoming more and more affordable, and in the long term optimised irrigation increases revenues. Data transmission by cable, Bluetooth or WiFi is free of cost, so local systems can work independently from the availability and affordability of services.
Digital readiness of target users	The maintenance of sensors and transmission networks needs technical capacities that normally cannot be expected from farmers. Some manufacturers provide very robust and easy-to-maintain sensors. Some farmers mistrust automated irrigation and prefer to change irrigation schedules according to their experience, so the introduction of these technologies needs training and sensitisation (Schnetzer and Pluschke, 2017; Elsaesser, 2020).
Digital readiness of implementing organisation/ business	The implementation of such technology needs a high level of expertise on the technical and also on the agricultural side. A network of maintenance service providers needs to be implemented for sustainability reasons.
Issues to note	Smallholder farmers often live in remote areas which are the last to be reached by basic services. So sensor systems need to be able to operate with solar energy, independently from the grid. Switching to solar pumping eliminates the cost of fuel. This often means farmers over-irrigate, which not only affects local water resources but also decreases yields. Automation of irrigation can be a remedy here.

Chameleon handheld soil sensor

FarmShield™ FarmSpear™ sensor

Seabex mobile monitoring platform

Figure 11 Examples of monitoring sensors and platforms

CLUSTER 12

BLOCKCHAIN FOR TRACEABILITY AND TRUST

Technologies	Blockchain
Value chain steps	Traceability, Farm to fork
Use-cases	Traceability
Description	Blockchain is an emerging digital technology allowing ubiquitous transactions among distributed parties or value chain steps. Supply chain traceability is one of the most important problems faced by all organisations globally. Commodities need to be tracked from farm to fork, and this needs databases and automation through digital scales, barcodes, QR codes and scanners. All information can be stored in a centralised database system and this, in principle, is sufficient. But central databases can be corrupted, and data can be intentionally falsified. They are thus vulnerable to fraud, especially when certified products can generate higher revenues. Blockchain technology introduces a secure way to store information: all sorts of actions are processed, verified and stored in a growing list by a distributed network of computers. This can be any type of information, such as financial transactions, contracts, shares or land register entries. Compared to conventional databases, blockchain has three main advantages. First, entries in the database are not located on a single server (e.g. a bank or public authority), but are distributed across many computers, which makes the data more secure against manipulation and attacks. Second, all entries are cryptographically encrypted and cannot be changed. New information is added to the existing block of data, old information is never overwritten. A chain of data blocks is created – a blockchain. As a result, changes remain traceable and transparent. Finally, blockchain technology can protect users' identities: codes can be stored for each blockchain element instead of names. The traceability and transparency of the entries ensures trust between users and enables transactions between unknown parties without the need for central control. However, a disadvantage is that data cannot be easily corrected. For more information on blockchain see CTA (2018).

The Indian HARIT Ticker platform uses blockchain technology to protect certification information for urban compost, but the numerous users frequently enter data incorrectly and cleaning the data is time-consuming and difficult.

SourceTrace offers the blockchain and AI-based traceability solution TraceNext in Bangladesh. This software solution enables full visibility into the agricultural and food value chain, with touchpoints across every stage from farm to retail. On their DataGreen platform they combine the solution with farmer profiling and certification. Integration of technologies such as GIS and IoT make it to a one-platform solution for agribusinesses.

Examples

BreadTrail from Trinidad, developed as an open-source project, comprises a mobile app compatible with Android and iOS, and a back end system that uses blockchain to provide unchangeable and transparent farm-to-fork traceability for everyone in the supply chain from farmer to consumer. In the banana value chain, BreadTrail records arrival information, the techniques used to process the fruit, protection such as wrapping or using polythene bags, and all other stages in the supply chain. The product's trail through the chain can be visualised by scanning the barcode, and the information is accessible for end user customers or companies through an app.

FoodPrint (see Cluster 13) uses blockchain technology for its digital farm-to-fork supply chain platform.

Implementation and setup

Blockchain solutions can be developed with any popular programming language. A blockchain is a combination of several technologies, including cryptography, distributed ledger technology, peer-to-peer (P2P) network programming, database storage and sharing, network communication and notifications, back end services, user interface components and others. So building a complete blockchain product may require more than just one programming language. He (2020) gives a beginner's guide to blockchain development.

To introduce blockchain technology in supply chain management or traceability, it is also necessary to equip a business with digital scales, barcodes, scanners, etc., to avoid having to manage erroneous input data.

Cost

The setup of a traceability system normally needs IT expertise, as well as deep insights into the target agribusiness. Costs are mainly related to the development of the supply chain hardware and software environment that provides data to the blockchain. Blockchain technology implies the use of many servers and the exchange of a lot of data, so it consumes a lot of energy and resources, ultimately creating additional costs.

Digital readiness of target users

The target group can be anyone in the value chain from producer to consumer, or in the supply chain from agro-dealer to farmer. In principle, traceability and supply chain management solutions make all stakeholders' lives simpler. However, technical understanding is needed to operate the devices.

Digital readiness of implementing organisation/ business

The development of blockchain-based systems needs sound programming skills. Blockchain technology is usually developed by universities, research centres or big players such as IBM. There are only a few off-the-shelf SmartTech solutions commercially available, but their implementation in a given context is not more complex than any other traceability or supply chain management software.

Issues to note

The problem for LMICs is that these technologies consume a lot of energy and bandwidth. A robust database running on a secure cloud server is usually the more stable and sustainable solution.

Many solutions that claim to be based on blockchain technology would, in reality, also function without.

Some argue that blockchain is over-hyped, e.g. Vota (2019a): “Distributed ledger technology was last year’s darling with everyone trying to ride that hype train. This year, we are over blockchain, as we found no impact from any pilots. It is now dropping out of the hype cycle, its use-cases limited to traceability and Facebook payment fantasies.”

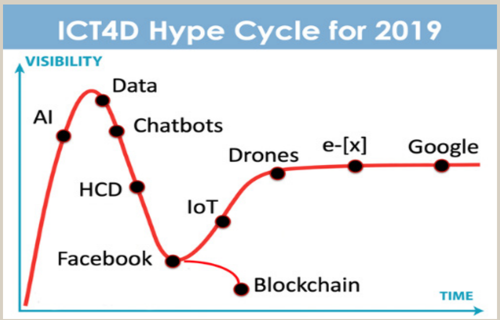


Figure 12 The 2019 ICT4D hype cycle. Source: Vota (2019a)

Figure 13 SourceTrace mobile platform

CLUSTER 13

END USERS BENEFIT FROM AGRICULTURAL INTELLIGENCE

Technologies	Artificial intelligence, Machine learning, GPS, Apps, Websites
Value chain steps	End customers, All value chain steps from production to consumer
Use-cases	Traceability, Precision farming
Description	To address the problems of hunger, malnutrition and food waste, the demand has to be analysed and understood. If the right amount of product can be provided to markets at the time and place they are needed, losses can be minimised and product freshness maximised. AI and ML algorithms enable us to create predictive models that can help estimate consumption patterns, which allows customers to receive the freshest produce possible. Agricultural products cannot be produced like factory products; they need time to grow and mature. So demand from end customers influences the production behaviour of farmers. Agricultural intelligence can help to optimise the various processes of production, harvesting, processing, transport and marketing, as well as traceability throughout the value chain.

Examples

Aibono is India's first AI-powered fresh food aggregator, pioneering the Seed-To-Plate platform that synchronises real-time production with real-time consumption of highly perishable fruit and vegetables using predictive analytics, precision farming and just-in-time harvests. This empowers communities of farmers to achieve twice the yield, twice the income and less than half the waste as before, by giving them precise insights derived from AI and shared farm intelligence on what to produce and how to produce it, while also enabling retailers and consumers to source super fresh farm produce all year round from a traceable aggregated source.

Ajaoko Agritech (Nigeria) is an online food and agri-marketing and capacity building platform that allows end consumers to get products directly from farmers, while giving farmers quick and easy access to inputs, professional agri-based services, tailor-made training, and the latest research information communicated clearly.

FoodPrint is a digital farm-to-fork supply chain platform for smallholder farmers and end customers in Africa. Farmers register with FoodPrint and grow their crops. When the harvest is collected, they log it in to the system. The produce then is transported to a broker/market and stored in a cooled storage room. Everything is tracked using blockchain technology to ensure transparency of origin and of the cold chain. End customers can scan the QR code attached to the fruit or vegetable (or crate) and see all the information, starting with the farm where it originates.

Implementation and setup

The creation of agri-intelligence platforms is among the most challenging developments in D4Ag. These platforms can combine all sorts of technologies and use-cases. The term "agricultural intelligence" can also be used for simpler solutions, such as tracking solutions introducing traceability.

There are no off-the-shelf products, and agricultural intelligence solutions need to be adapted to the specific setting. This needs high levels of expertise and a sound understanding of the value chain as well as the markets.

Most solutions that benefit customers start at the farmer level, whether through providing QR codes to label produce for customers' convenience, or modelling market demands that translate to planting recommendations for the farmer. Smart technologies with AI and ML can be used to create predictive models. Such systems usually work best if there is already an advice system in place in which farmers trust. These systems allow the creation of connections between farmers and customers, and benefiting both sides. Feedback mechanisms in both directions are necessary to help optimise the services.

Cost	The setup of such services requires high IT development capabilities, stable connection to the internet and a skilled crew, all of which are serious expenses. However, in most cases there is no need for investment in costly equipment, expensive sensors or machines. Once the system is developed and setup, operational costs will most likely be minimal.
Digital readiness of target users	Most services require customers to have internet access in order to check on updates, connect with farmers, place and track orders and leave reviews. Some solutions might require a smartphone with data connection and ability to scan QR codes. The GPS functionality of the smartphone can help connect farmers with their closest markets, reducing transportation costs and increasing product freshness.
Digital readiness of implementing organisation/ business	Extensive IT expertise is required for the development and setup of such systems. Continuous costs arise as tracking of products needs materials such as barcode stickers, scanners, internet connectivity and cloud servers.
Issues to note	The delivery of information to consumers relies heavily on access to a smartphone or a computer with stable internet access, which might be a problem in some locations. Such solutions logically target consumers in more developed urban areas.

4. TECHNOLOGICAL TRENDS

4.1 Artificial intelligence

Artificial intelligence is approaching the peak of inflated expectations. Organisations, donors and implementers all want to incorporate AI into their AgriTech solutions. USAID (2018b) has issued a guide to "Artificial intelligence in Global Health"; CTA (2019b) dedicated an issue of its bulletin Spore to this technology; and a large number of articles comment on the future of AI for agriculture. However, in reality most solutions claiming to use AI are only doing basic ML, if not just old-school statistical analysis with better branding.

Real AI does not provide recommendations to decision makers – AI actually decides – making it different from a decision support system or basic information system. But AI should not be seen as a means to replace human decisions – AI should empower humans and enhance the sustainability of their lives.

4.2 Blockchain

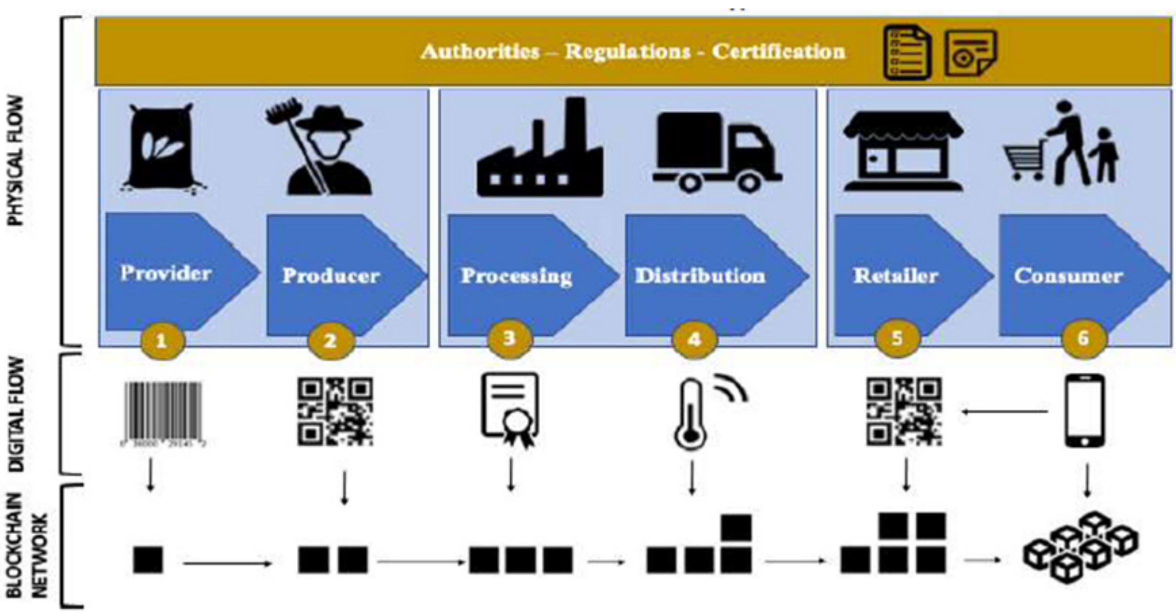


Figure 14 The use of blockchain technology along the value chain. Source: Kamilaris et al. (2019)

Blockchain has been on everyone's lips as a promising technology for several years now. CTA's 2018 *ICT Update* bulletin was dedicated to this technology.

While there are real potentials in finance and law, blockchain is rarely a good solution for agriculture, and especially not in LMICs where access to electricity, internet and technology is often difficult.

4.3 Chatbots

Chatbots, such as the well-known Amazon Alexa, are a good match for e-extension services. Chatbot development platforms like WotNot, ChatFuel and Gupshup make it fairly simple to build a chatbot from scratch. While the hype may have passed, the practicalities are just emerging, with easy and transparent reach for projects wanting to include that technology. But – a chatbot is only as good as the content of its knowledge base.

Facebook chatbots are a popular way to answer basic questions or help farmers apply for government support services. SMS text message chatbots can also help private sector companies develop new business leads and educate extension agents on their services.

On the user's side, chatbots usually need a smartphone, but voice-based bots can also be used with simple phones. However, the use of chatbots in agriculture still calls for acceptance of this new type of technology among the farmer population (Vota, 2019b).

4.4 Big data, open data, real-time data, dashboards

Without data, there can be no ICT4Ag, SmartTech4Ag or D4Ag. ML and AI technologies heavily rely on data, and sensors automatically fill the databases. Local weather forecasts, index-based insurance and pest detection would not function without big data.

A push for open data has resulted in successes in many countries (Alais, 2016) with positive results (Verhulst and Young, 2018). Some satellite data relevant to agriculture can be freely downloaded. For example, the FAO Water Productivity Open-access Portal (WaPOR, https://wapor.apps.fao.org) is used as a source for many SmartTech solutions targeting production, such as PlantVillage's Nuru app. The WaPOR project recognises that there are barriers to use for some stakeholders: for example, farmers must be able and willing to adopt innovative practices based on the ICTs the portal uses. The enabling environment for uptake of the information and suggestions provided by WaPOR determines the project's ultimate success (FAO, 2021).

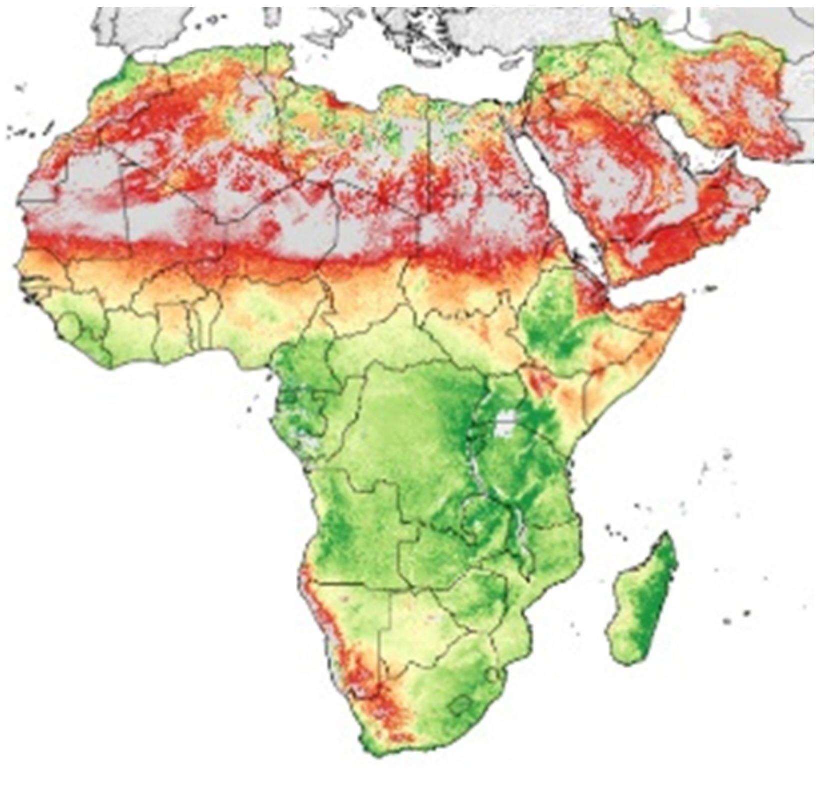


Figure 15 The FAO WAPOR database

Today, decision makers want data dashboards as a customisable interface. A dashboard provides at-a-glance summaries or data visualisations (e.g. graphs) of key performance indicators or progress reports. It is often accessed via a web browser, and is usually linked to regularly updated data sources. This type of front end allow users to quickly and interactively draw statistical analyses from a large amount of available data.

4.5 Drones

The potential of drone applications for agriculture is still very high. But this technology is developed in high-income countries, and is only being slowly adopted by agriculture in LMICs. It is now known exactly when and how drones can be useful for agriculture. However, in many ACP states there are no drone regulations, and this effectively translates into drone bans (Figure 16).

The operation of drones, and especially the analysis of drone-based products, needs a high level of technological expertise. Most successful drone applications for agriculture provide sensor-based modelling of crop types, crop water demand and crop health.

Also, drone-based application of pesticides or fungicides is difficult to operationalise as most drone cargo loads are very limited.

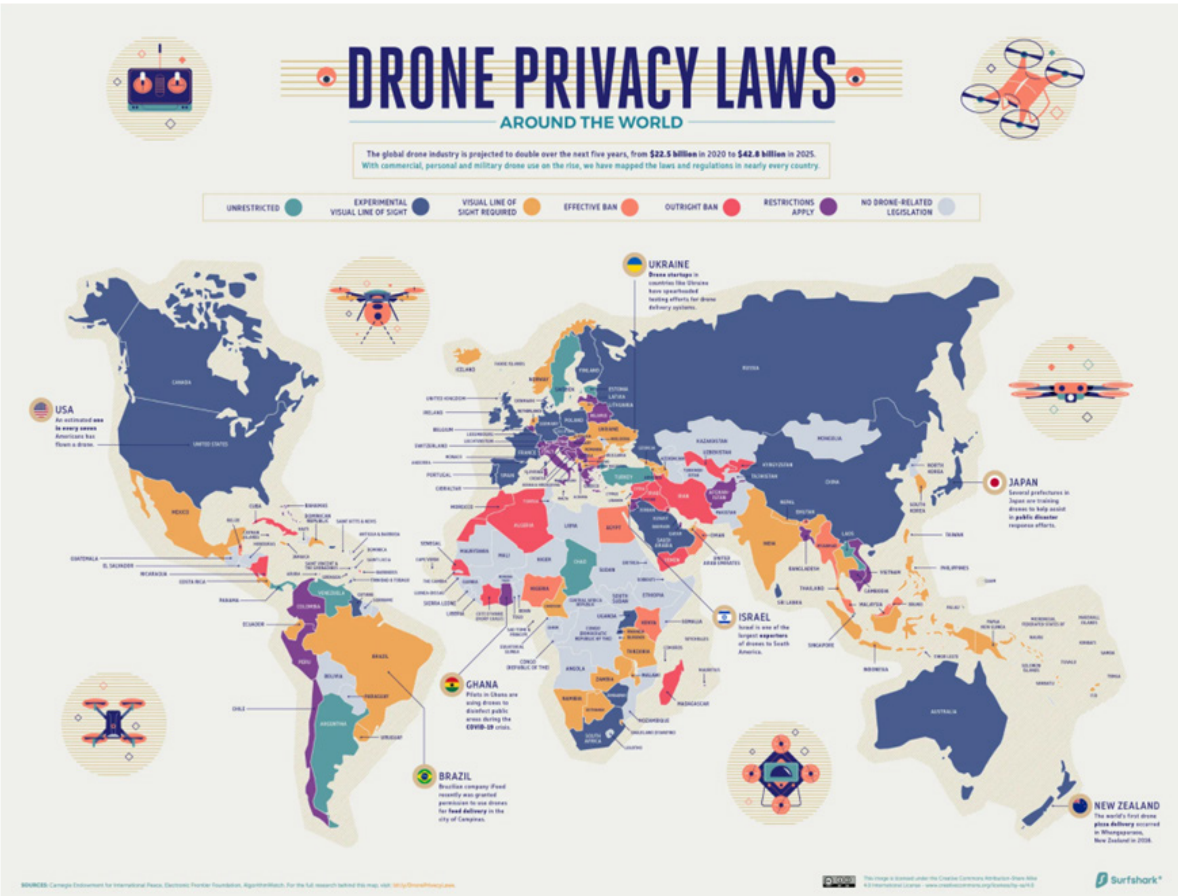


Figure 16 Drone privacy laws of the world. Source: Carnegie Endowment for International Peace, in Visual Capitalist (2020)

4.6 Remote sensing

Remote sensing is still one of the most interesting fields for agriculture. Ground-based sensors as well as drones and satellites deliver continuous, precise data about spatial variations of different parameters. Specialised sensors such as radar, LIDAR and NIR can help to detect soil moisture, differences in plant health, and precise digital elevation models. The possibility to automatically repeat drone flights, and the low price or even free access to satellite imagery, are accelerating the development speed of this market, and new use-cases are being developed at breath-taking speed. Remote sensing for agriculture is thus seen as a very promising field. GIS technology is usually needed to create remote sensing-based products.

4.7 Internet of Things

IoT is a very promising field of technologies for agriculture, especially for production, processing, transport and storage. Traceability can be achieved by using IoT-enabled devices collecting all the necessary information. IoT devices are also at the basis of all ML and AI solutions. All automated and data-driven processes need sensors to be installed, and if these sensors transmit to servers, the devices can be described as IoT-enabled.

However, according to the GSMA Internet of Things Programme, on the current IoT global coverage map the continent of Africa is still almost entirely blank (Figure 17).

Figure 17 Mobile IoT deployment map. Source: GSMA (2020b)

4.8 Social media

Ten years ago, Facebook was breaking news in Africa. A few years later, the community realised there were data security problems (Woodard, 2016), the digital coloniser problem (Kariuki and Nash, 2017), and the fake account problem (Vota, 2019c), among others. The question is, should Facebook be still promoted? Should it be accepted because that is where people are (Dumpert, 2018), and where user-generated content starts? In many African countries, Facebook is the main app used by smartphone users, so it is still a good way of disseminating messages to a large audience. For example, the authors found that in Niger, in 2019, an agricultural video shared by the national extension service's Facebook site reached thousands of farmers within a day, and after three days 10,000 farmers watched the downloaded videos on their colleagues' smartphones.

In principle, there are alternatives to Facebook, but it is a general problem that the power of a communication platform rises with its number of users.

A data protection problem associated with the use of WhatsApp has forced many companies to prohibit their employees from using this instant messaging service on company-owned hardware (Vota, 2018). WhatsApp remains however a very important communication chanel in ACP countries.

4.9 Google

The above issues also apply to Google. But it is nearly impossible to avoid Google products as they penetrate all technologies, use-cases and people's lives. Google Android is still the primary OS for smartphones; Google Maps, Gmail, Google Groups, Google Translate – all these products are difficult to avoid. And Google's futuristic investment Google Loon aims to bring high-speed internet bandwidth, everywhere, and free.

5. STAKEHOLDERS, PROGRAMMES AND INITIATIVES

This section lists stakeholders, programmes and initiatives with activities in the field of D4Ag, ICT4Ag and SmartTech4Ag. Some of them regularly organise hackathons, some maintain incubators and accelerators, some implement their own digital solutions, and some provide funding for implementers of AgTech solutions.

5.1 African Tech Hubs

Since 2016, GSMA has been mapping the number of tech hubs in Africa, which they describe as "the backbone of Africa's tech ecosystem". Of all these hubs, roughly half are tech incubators, accelerators, university-based innovation hubs, makerspaces and technology parks. Around 25% of the hubs are only offering coworking spaces.

This infrastructure is rapidly evolving, and countries with the highest density of tech hubs usually have the highest number of developers and thus are more technologically advanced. Figure 18 shows that in the ACP regions, Kenya, Nigeria and Ghana are the most advanced countries regarding ICT4Ag and D4Ag.

A more up-to-date but less detailed list can be found on the GSMA website (Giuliani and Ajadi, 2019). The leading country in 2019 in Africa by number of hubs remains South Africa with 59 active hubs, followed by Nigeria (55), Egypt (33) and Kenya (31).

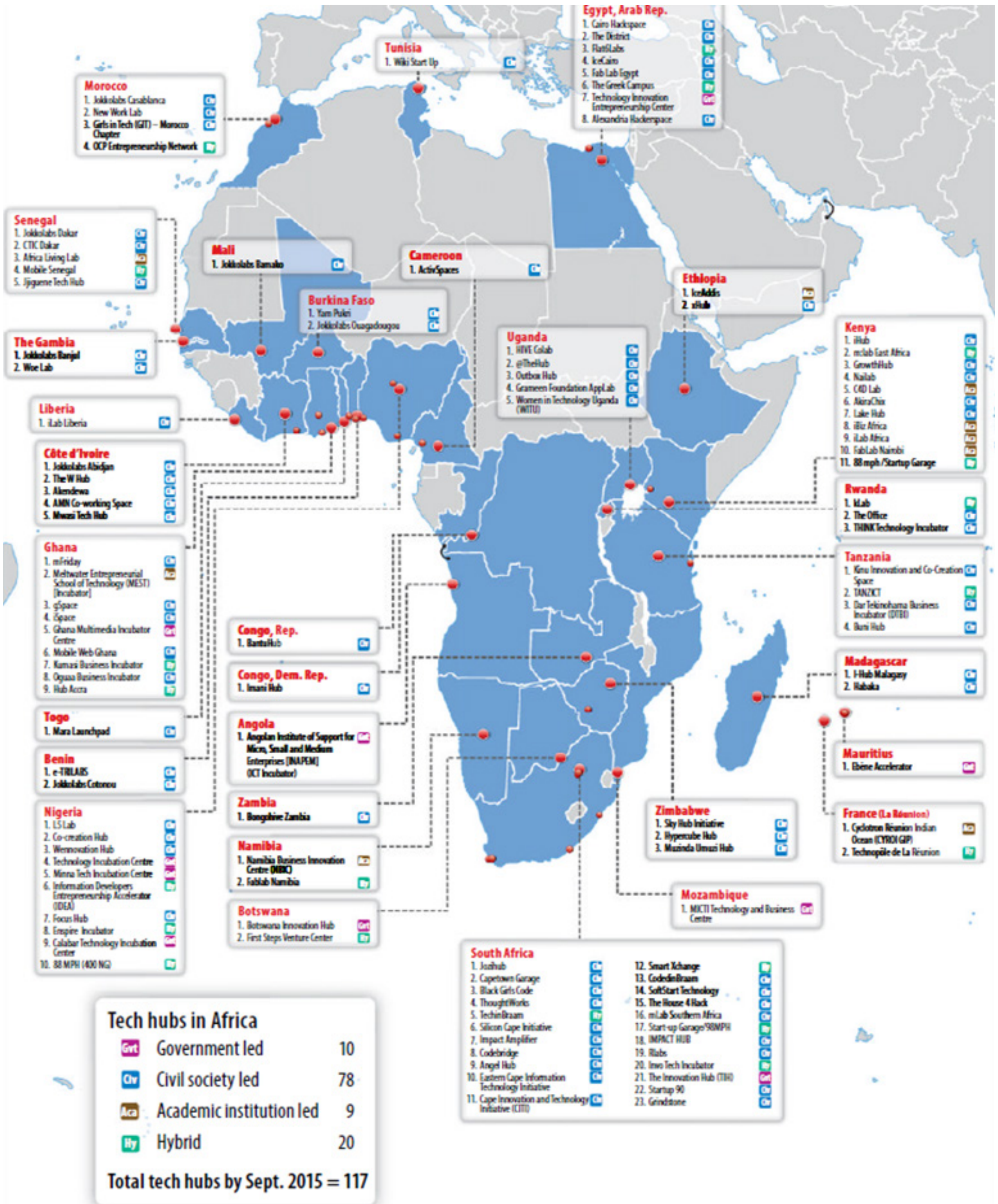


Figure 18 African tech hubs. Source: World Bank (2016), p. 230, Map 4.3

5.2 International stakeholders

AFD Digital Africa

AFD
AGENCE FRANÇAISE DE DÉVELOPPEMENT

As part of its "shared innovation" series, AFD highlights innovative programmes that have been created, developed or encouraged in its partner countries.

https://www.afd.fr/en/actualites/digital-africa-seed-funds-start-ups

AGRA

AGRA undertakes demand-driven interventions that leverage donor, private sector and government investments in agriculture. Its areas of intervention include digitalisation.

https://agra.org/grants/

AGRF Agribusiness Dealroom

This matchmaking platform facilitates partnerships and investments in African agriculture. It supports governments and companies with access to finance and partnership opportunities. The Dealroom is expected to attract close to 200 companies, 15 government delegations and 50 public and private investors exploring a wide range of investment opportunities.

https://agrf.org/dealroom/

AI4AI Initiative – Artificial Intelligence for Agricultural Innovation

The platform provides a nontechnical introduction into the domain of AI, presenting content that exposes users to the exciting world of AI to prepare for the future, where AI will be a major force in many industries.

https://www.ai4ai.net/

Bill & Melinda Gates Foundation

The Foundation **invests in tools and technologies that target the specific needs of farmers in sub-Saharan Africa and South Asia**. Digital farmer services are one of the main topics, and they provide grants for innovative solution proposals.

https://www.gatesfoundation.org/our-work/programs/global-growth-and-opportunity/agricultural-development

BioVision

BioVision aims to promote agroecological innovations and their dissemination in cooperation with local research institutions and the private sector; transfer knowledge and strengthen the capacity of local communities and organisations; and bring together different actors with a policy dialogue to change framework conditions.

https://www.biovision.ch

CABI – Centre for Agriculture and Biosciences International

CABI is an international, inter-governmental, not-for-profit organisation working in the field of crop health, invasive species, value chains and trade. It promotes digital developments to bring science-based agricultural knowledge to millions of smallholder farmers, helping to increase their yield. The PRISE Pest Risk Information Service uses a combination of earth observation technology, real-time field observations and plant-pest life cycles to deliver a science-based service for sub-Saharan Africa. Facilitating access to data and knowledge is the main objective of the developed tools.

https://www.cabi.org/what-we-do/digital-development/

CGIAR – Consultative Group on International Agricultural Research

Among many research areas, big data is a key topic; for example see https://www.cgiar.org/annual-report/performance-report-2020/cgiar-digital-strategy/

CTA – Technical Centre for Agricultural and Rural Co-operation

CTA was established in 1983 under the Lomé Convention between the ACP Group of States and the European Union Member States, and closed at the end of its mandate in 2021. One of its key focus areas was bringing forward the digitalisation of agriculture. For example, its **AgriHack Talent** initiative aimed to support ICT innovation and entrepreneurship in **agriculture** in ACP countries, targeting young entrepreneurs aged 18–35. Useful documents and resources are archived on its website.

https://www.cta.int/en/digitalisation

ENABEL Wehubit – Boosting Digital Social Innovation

Through the Wehubit programme, Enabel funds digital initiatives originating from the private sector, non-profit organisations or the public sector in the partner countries of the Belgian Development Cooperation. Wehubit supports scaling-up and replication of 'digital for development' initiatives via grants, loans and equities. Calls for proposals are regularly launched on the Wehubit website.

https://www.enabel.be/content/digital-development-what-enabel-doing

EU H2020

Development Smart Innovation through Research in Agriculture.

Funding programmes started in 2014 and ended in 2020. Some activities are still ongoing.

https://ec.europa.eu/programmes/horizon2020/en/home

EU DeSIRA – Development Smart Innovation through Research in Agriculture

The DeSIRA initiative has three pillars: Innovation in agriculture; Research infrastructure conducive to innovation; and Knowledge and evidence to feed development policies. DeSIRA aims to put more science into development considering that the solutions to achieve the SDGs are context specific.

https://ec.europa.eu/international-partnerships/programmes/desira_en

FtMA - Farm To Market Alliance

An alliance of six agri-focused organisations (AGRA, Bayer, Rabobank, Syngenta, WPF, YARA), working with local private sectors to deliver a wide range of comprehensive products and services tailored to the needs of farmers in Kenya, Rwanda, Tanzania and Zambia.

https://ftma.org/

FAO Global Alliance for Climate-Smart Agriculture

GACSA is an inclusive, voluntary and action-oriented multi-stakeholder platform on climate-smart agriculture (CSA). It aims to catalyse and help create transformational partnerships to encourage actions that reflect an integrated approach to the three pillars of CSA.

http://www.fao.org/gacsa/en/

GIZ MakeIT in Africa

This Digital for Agriculture initiative (2017–2020) provided support to AgTech startups in Nigeria, Kenya, Rwanda, Tunisia and Ghana by improving market access for AgTech solutions, expanding opportunities, building capacities, developing business models and brokering partnerships.

https://www.giz.de/en/worldwide/57293.html

GIZ: SAIS – Scaling digital agriculture innovations through start-ups

SAIS targets start-ups across Africa that provide innovative digital solutions for the agricultural and food sectors, but have not yet reached scale. The selected start-ups will be supported through individual measures for business expansion or development. This will be done by developing organisational, financial and technological capacities to increase readiness among business partners and investors to invest.

https://www.giz.de/en/worldwide/83909.html

GODAN – Global Open Data for Agriculture and Nutrition

This partner network's mission is to eradicate hunger, improve nutrition and achieve global food security for millions of people across the globe through unlocking the power of technology and open data.

https://www.godan.info/

GSMA – Groupe Speciale Mobile Association – AgriTech Programme

GSMA AgriTech brings together and supports the mobile industry, agricultural sector stakeholders, innovators and investors in AgriTech space to launch, improve and scale impactful and commercially viable digital solutions for smallholder farmers in the developing world.

https://www.gsma.com/mobilefordevelopment/agritech/

Horizon Europe

Horizon Europe is the EU's key funding programme for research and innovation with a budget of €95.5 billion until 2027. It focuses on solutions tackling climate change, achieving the UN's Sustainable Development Goals and boosting the EU's competitiveness and growth.

https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

Horticulure Research Center

The centre provides grants for innovative solutions in horticulture agriculture. They do not yet have a strong digitalisation focus.

https://www.hriresearch.org/

ICARDA – Digitalisation of Research-for-Development

ICARDA is an organisation of the CGIAR undertaking research for development. Earth observation, big data and geomatics are one of its fields of research. The GeoAgro service provides freely available geo-data on agricultural crop indicators.

https://www.icarda.org/research/cross-cutting-theme/digitalisation-research-development

IFAD – International Fund for Agricultural Development

IFAD-supported projects connect poor rural people to markets and services so they can grow more and earn more. Its projects aim to transform rural communities economically and socially, and promote gender equality and inclusiveness. Its digitalisation projects mainly target financial inclusion.

https://www.ifad.org/en/

MercyCorps AgriFin

AgriFin leverages the power of digital technology, data and a global network of partners to build a brighter future for smallholder farmers and the people they feed. It designs, tests and scales digital services and products to boost their productivity and income, and build their resilience to climate change.

www.mercycorpsagrifin.org

MasterCard Foundation - Centre for Innovative Teaching and Learning in ICT

The Foundation launches initiatives to digitise Africa's value chains and improve digital skills among young Africans.

https://mastercardfdn.org/all/centre-for-innovative-teaching-and-learning-in-ict/

PRIDA – Policy and Regulation Initiative for Digital Africa

This joint initiative of the African Union, European Union and International Telecommunication Union enables the African continent to reap the benefits of digitalisation by addressing various dimensions of broadband demand and supply in Africa, and building the capacities of AU Member States in the Internet Governance space. PRIDA's overall objective is to foster universally accessible and affordable broadband across the continent to unlock future benefits of internet-based services.

https://www.itu.int/en/ITU-D/Projects/ITU-EC-ACP/PRIDA/Pages/default.aspx

SNV – Digital Transformation of SMEs

SNV looks at effective matchmaking between SME clients and digital solution providers, to enable SMEs to tap into opportunities presented by developments in the digitalisation space.

https://snv.org/update/digital-transformation-smes

USAID D2FTF – Digital Development for Feed The Future

This three-year collaboration between the US Global Development Lab and the Bureau for Food Security aimed to advance the ICT4D for agriculture field. D2FTF focused on four categories of digital tools: precision agriculture (including sensor technology), digital financial services, data-driven agriculture, and ICT-enabled extension.

https://www.usaid.gov/digitalag

VC4A – Venture Capital for Africa

VC4A strengthens the global start-up community by connecting entrepreneurs creating innovative and scalable businesses with the knowledge, network and funding they require to succeed.

https://vc4a.com

World Bank ID4D

This initiative supports achievement of the SDGs by helping countries realise identification systems fit for the digital age. They provide technical standards, guidelines for practitioners, procurement and diagnostics and a qualitative research toolkit.

https://id4d.worldbank.org/

World Food Programme Innovation Accelerator

The WFP Innovation Accelerator sources, supports and scales high-potential solutions to end hunger worldwide. WFP provides entrepreneurs, start-ups, companies and NGOs with access to funding, mentorship, hands-on support and access to WFP's global operations. Through the Innovation Accelerator, WFP is leveraging unprecedented advances in digital innovation—such as mobile technology, artificial intelligence, big data and blockchain.

https://innovation.wfp.org/

6. RISKS AND CHALLENGES

6.1 Social risks

Availability of and access to digital technology is generally lowest for the poorest part of the population of ACP countries. Basic services such as electricity, telephone network access and internet are better developed in urban areas, while in remote areas, where small-scale farming is ubiquitous, they are barely developed or have not yet arrived at all. If ICTs are available, the technological leap is still daunting, and a large part of the population will be unable to utilise the technology to its full potential. Not every farmer has a cell phone, or can read and understand text messages. Here, the introduction of ICTs can lead to further marginalisation if it is not done with care. The intention to "leave no-one behind", contained in the 2030 Agenda for Sustainable Development, risks being missed.

People living in rural areas, especially farmers in developing countries, face a "triple divide". In addition to the digital and urban-rural divide (services, networks, infrastructure), there is the gender divide, which has the effect of relegating rural women to the most marginalised position when it comes to accessing and using ICTs. The *Gender in Agriculture Sourcebook* (**World Bank**, 2009) underscores the potential for ICTs, when used in a gender sensitive way, to help bridge these divides and advance the processes of social inclusion, with tangible results, including a narrowing of the economic and social divide between women and men (Figure 19).

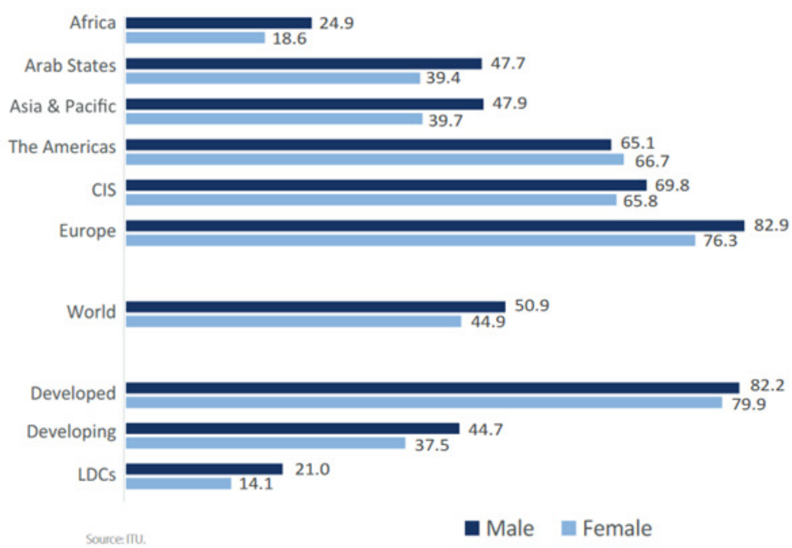


Figure 19 Estimated internet penetration rate for men and women in 2017. Source: FAO (2018a)

ICT technologies such as community radio still play a very important part in outreach to the poorest. But ICT cannot fully replace field visits or training sessions on agricultural management practices. These continue to be an important instrument in getting information across, especially when it comes to explaining complex topics. E-learning might be a good means to allow people access to knowledge, but it is only equitable if everyone can access it.

Technological and logistical capacities are needed among the target group for the operation of ICT solutions, and for the interpretation of data in order to derive the correct decisions. Farmers have to be appropriately trained, which may prove difficult if they are illiterate. Traditional methods such as lead farmers and/or advisory services can help in training farmers on how to make use of ICTs.

6.2 Technological risks

ICT offers numerous technologies that are growing exponentially in number and performance. For a given problem, there are usually several potential technical solutions. Blockchain, RFID and LIDAR technologies sound like a panacea; technologies such as AI and ML may appear to offer infallible solutions – with attractive, colourful outputs – but in reality they are often unsuitable for solving the problems of farming. The very high technologies are particularly difficult to understand, implement and manage. While in the past many SmartAg solutions have been advertised using buzzwords such as blockchain, AI or ML, in practice the underlying technologies are much simpler. In many cases these technologies could be dispensed with, but their use often leads investors and customers to believe that the solution is modern and innovative. In Southeast Asia in particular, and also in Nigeria, the terms are often overused.

Many digital solutions require adequate internet availability and seem to work perfectly in a pilot environment, but subsequent scale out reveals the weakness of the design. Video streaming, for instance, needs high internet bandwidths, and even opening a Facebook site in a browser can be a time- and data-consuming task.

App development frequently targets the latest version of operating systems, but farmers often have old phones that cannot be updated. To be usable by a large target group, apps should be able to run on old Android versions and on smartphones with low resources.

Agricultural work generally has a lot to do with dust, dirt and water – not the best environment for state-of-the-art technology. Although robust end devices are available for outdoor use, they are usually too expensive for smallholder farmers.

The maintenance of software is expensive, and continuous costs may arise from operating a helpdesk and fixing bugs. Also, software will be developed for a certain version of an operating system or a certain web service, and needs to be updated for future releases in order to remain compatible. A software company needs to have the financial capacities (a feasible and scalable business model) and a competent team to guarantee the sustainability of its products.

6.3 Financial risks

The acquisition of digital technologies is often associated with high costs for actors in horticultural value chains. The operation of sensor and transmission networks, satellite data acquisition, or the purchase of RFID chips is expensive. The number of examples where the costs for digital services provided are fully covered by farmers is low. Business models exist mainly for software that targets larger, commercial horticulture businesses. Many technically successful solutions are not financially sustainable and work only for the duration of the implementing project. The landscape of currently available digital applications for the horticulture sector shows that services have to be very cheap, or offered for free, in order for smallholder farmers to benefit from them.

6.4 Low level of ICT expertise

In contrast to standard software like word processing or spreadsheet programs, the horticulture sector usually requires highly adapted digital solutions. The diversity of value chains, regional cultural differences, climate, soils, and threats from pests/diseases and natural disasters all need adapted solutions. The variety of languages in the ACP states and the different horticulture systems further complicate the provision of standardised technical solutions. Developing new technical solutions, or adapting existing solutions to a specific context, requires IT expertise, which frequently is not sufficiently available yet in the target regions. Most local IT experts work for telecommunications companies and the banking sector, as the agricultural sector is considered a less attractive field of activity. Generally, people in poor countries go to school and university to escape from agriculture, and there is a need to convince those people of the attractiveness and potential of agriculture.

In addition, the difficulties in most ACP rural areas of obtaining IT hardware and related consumables, and the necessary maintenance, should not be underestimated. But on the other hand, the development of software by international companies entails the risk of dependency and high costs, and frequently results in a low level of local adoption.

Without the necessary expertise, it is difficult to develop ICT applications that integrate seamlessly into agricultural value chains. The author's experience from many international projects reveals that the most innovative ideas for African D4Ag solutions come from African ICT graduates who grew up in farming communities. They know farmers' needs and how they think, and can best predict their behaviour. The implementation of ICT solutions requires cultural sensitivity and deep understanding of the perspective of users, who may be illiterate smallholder farmers or degree-holding agronomists.

6.5 Risk of data misuse

ICT technologies collect, store, analyse and share data. This data can contain sensitive privacy-related information of a certain value, and should therefore be protected and not shared with third parties unless by appropriate agreements. Misuse of data by governments, the private sector or even by NGOs must be avoided through appropriate regulatory frameworks. Many countries today have regulations in place; for countries lacking laws and guidelines for data use, low-level principles can be applied (see Box 2).

Guidance and regulations on data protection

Example of sources for assessing a country's situation regarding data protection include:

- Generic guidance (see section 2; e.g. GIZ Responsible Data Principles: GIZ, n.d.; 2019)
- Existing regulations for unmanned arial vehicles/drones (FSD, 2017; FAO, 2018)
- Existing regulations for data privacy (Africa Data Security Conclave, 2020; UNCTAD, 2022)
- Existing regulations for cybersecurity (AU, 2014; ITU, 2017)
- Availability of Cybersecurity Incident Response Teams (ITU, n.d.)
- Global Innovation Index (WIPO, 2021)

There are also digital readiness indices by country, from various sources. The most comprehensive index is the GSMA Global Mobile Connectivity Index (GSMA, n.d.b), with all data downloadable in Excel format. Smart Africa clusters sub-Saharan countries according to their digital readiness (SmartAfrica, 2020); and the EU-funded Policy and Regulation Initiative for Digital Africa (PRIDA) has developed the Digital Agriculture Readiness Index (DAgRI) (EC, n.d.).

6.6 Poor enabling environments

Digital technologies can help African farmers increase their profitability and reduce their environmental impact; however, the development of this sector needs support through public policy. A top-down approach is dangerous here: transformation of the sector must be intrinsic and cannot be forced by governments. However, governments can stimulate this development by creating the space needed for it to happen, and enabling environments are key to success. Digital solutions work most efficiently in the agricultural context when there is a reliable mobile network available, when e-payment systems are accessible, and data privacy policies and drone regulations are in place. Mobile data prices in India, for instance, are much lower than the African average, so data usage is higher and the market for D4Ag solutions is better developed. Education also plays a role: in Ghana, a good example of a successful D4Ag market, ICT is a mandatory subject in secondary schools. The non-availability of tech hubs (incubators, accelerators, makerspaces, and to some extent co-worker spaces) is another obstacle to development of the sector. Figure 18 shows African countries with the number of available tech hubs in 2019. The number of national IT professionals follows this pattern, so the process of digitalisation is more advanced in these countries.

Table 2 gives an idea of the modernity of technology by region. The map in figure 7-2 completes this information by the mobile connectivity index score. This is the percentage of people having a mobile connection. In the agricultural context these values have to be taken with caution, as the values vary greatly between urban and rural areas. GSMA Intelligence, Index Mundi and/or World Bank provide databases which list these and other data disaggregated by country. Additional sources for assessing the digital readiness of a country are listed in Box 2

Percentage of mobile connections in LMICs, by technology, by region[18]

Region	Technology	2019	2025
Sub-Saharan Africa	2G	45%	12%
	3G	46%	58%
	4G	10%	27%
	5G	0%	3%
Asia Pacific (South and Southeast Asia)*	2G	27%	7%
	3G	25%	14%
	4G	48%	68%
	5G	0%	11%
Latin America and the Caribbean	2G	17%	5%
	3G	35%	21%
	4G	47%	67%
	5G	1%	7%
Middle East and North Africa	2G	31%	10%
	3G	40%	36%
	4G	29%	48%
	5G	0%	6%

Source: GSMA Intelligence, 2020. *Figure includes Australia. Note: totals may not add up due to rounding

Table 2 Percentage of mobile connections in LMICs, by technology and region. Source: GSMA in Phatty-Jobe (2020) p. 18

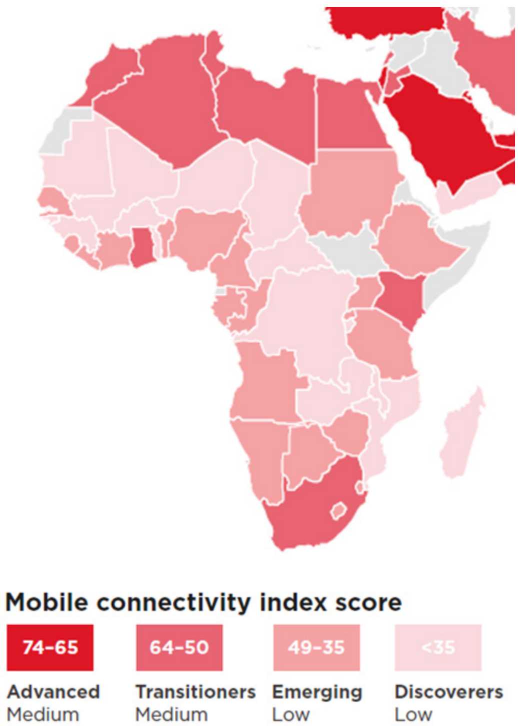


Figure 20 Mobile connections in LMICs, 2018. Source: GSMA in Phatty-Jobe (2020) p. 19

7. KEYS TO SUCCESS

ICT offers a wide range of technologies, and there is always an appropriate technical solution for a given problem. To find the most suitable technology, however, many factors must be evaluated: the end user's access to basic services such as grid and internet, their literacy level, access to technology and related know-how, as well as availability of financial resources and access to financial services. A solution targeting the smallholder farmer as a user needs a simpler and cheaper technology level than a traceability solution for a whole value chain. The step towards digitalisation for a company usually requires the establishment and implementation of an IT department. Well-trained personnel are key to success but this resource can be difficult to find, especially in rural areas.

The topic of business models is a much discussed one in this context. Classic business models for solutions targeting the smallholder farmer can rarely be found. Direct-to-farmer business models could still have a potential for financial sustainability because of the large potential customer base and pay-as-you-go models. But farmers in Africa often already struggle to cover the cost of a smartphone or data, so additional licensing fees or transaction-based costs become a real obstacle. Better access to finance can allow farmers to invest in technology and to benefit from new developments in the sector.

A few general keys to success are given below. They apply not only to the introduction of ICT-based solutions for the horticultural value chain, but also to other fields of agriculture. Taking these keys to success into account will increase the probability of implementing successful ICT solutions. They are derived from a large number of projects, documents and reports from other organisations, and from personal experience of the author.

- **Keep it simple for the end user.** ICT solutions should be as simple and user-friendly as possible. The most successful ICT solutions are those that anybody can handle. It is not necessary for the users to understand the underlying technology. GPS technology, for instance, is used by every smartphone owner, but not every user knows about satellite orbits and the theory of relativity. The solutions, especially apps, should be self-explanatory – not many users will read a multi-page tutorial before using an app. User experience (UX) is a new field of science that discusses intuitive user design of applications (itCraft, 2019; DesignKit, n.d.).
- **Select the appropriate technology**. ICT is a means of providing better services and streamlining existing processes. ICT offers a wide range of technologies, and there are usually several approaches that deliver the same result. State-of-the-art technology is not always the most effective option. Farming frequently takes place in remote areas where the service coverage for mobile phones is not complete, or the literacy of farmers is not high enough. In most cases, a mix of technologies forms the successful solution. For instance, remote sensing technology and machine learning can model weather alerts, while the localised message is still transferred to the farmer by SMS.
- **Create sustainable and affordable solutions**. Expensive digital services are not likely to be adopted by farmers. Free services, however, are often perceived as less valuable. Wherever possible, basic services should be offered for free, while advanced service levels should not be free of charge. ICT is a perfect means to reach a high number of stakeholders, which lowers the cost for the individual user. For SMSEs, the initial investment in digitalisation, such as traceability, may seem high, but the potential increase in effectiveness, access to new markets and associated increased revenue can quickly cover these costs.

- **Consider the local setting**. When designing a digital application for a specific target group, their access to basic services, their literacy level and local languages should be considered. For the user, it is essential that the software or service is provided in their own language. If literacy is low among users, voicemail technology, pictograms and photos can offer a solution.
- **Attract young people to modern farming**. Modern technologies can be an incentive for young people to stay in rural areas and engage in activities that promote horticultural value chain development. Literacy rates and technical affinity are generally higher among younger generations. Access to smart technologies can trigger the transformation of the farming sector.
- **Mobilise local ICT capacities**. ICT capacity can be found, developed and mobilised in all capitals and larger cities worldwide. Globalisation gives access to state-of-the-art ICT know-how which stimulates the emergence of local IT ecosystems. This process can be initiated and accelerated through local or regional hackathons, IT and programming competitions. One problem is that while IT know-how is mostly found in urban areas, the need for ICT4Ag arises in rural areas. One key to development is to decentralise knowledge and capacities, and D4Ag can be a driver for this.
- **Make use of existing solutions where possible**. There are many examples of successful ICT projects in the horticulture sector. Learning from successful projects is valuable, as are the lessons learnt from failures. Sometimes readily available software can be the more appropriate solution. It is cheaper than developing a custom-tailored product, and prevents the implementer from repeating errors and from creating solutions that are too complex. Case-specific software development should be avoided where possible. If IT development is unavoidable (e.g. for traceability or database development), cooperation with local IT firms can enhance its sustainability. Where the customer and IT service provider work closely together, a successful outcome is more likely. An IT firm with knowledge and experience in agriculture is more likely to come up with a suitable solution.
- **Use local products with local support**. For sustainability reasons, hardware and software should be sourced locally where possible. There are highly specialised international providers of agricultural software, and the risk that local resellers exist and dominate the market is high. Development projects should support local IT development where possible. In Nigeria and Kenya, for instance, where many D4Ag solutions can be found, the number of software developers is relatively high and so is the salary level (Figures 21 and 22). At the bottom of the list of the top 17 software development countries in Africa is Ethiopia, with only 72 developers per million population. Logically, there are more than 40 African countries with even fewer.

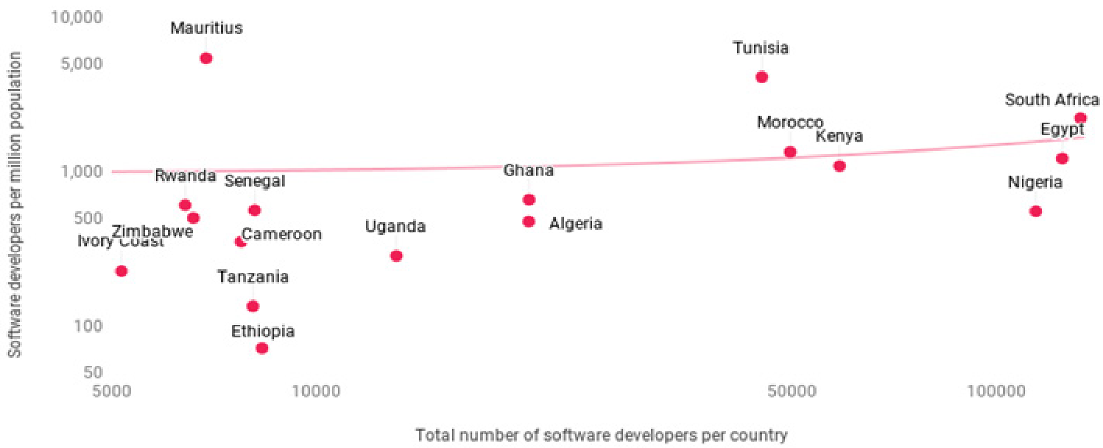


Figure 21 Developer landscape in Africa: Top 17 software development countries in Africa

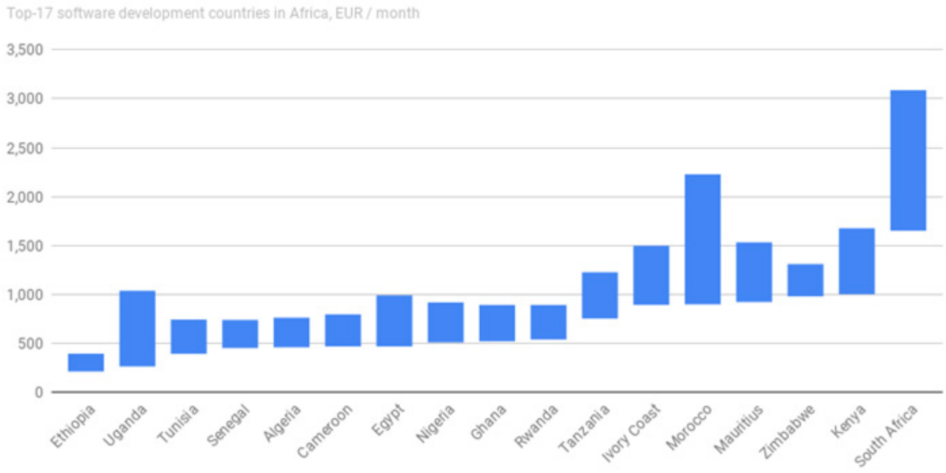


Figure 22 Salary ranges for software engineers of top 17 African countries (EUR/month)

- **Develop a feasible business model.** For the development of a viable business model, a comprehensive analysis of various factors is necessary. If the ICT solution targets the poorest and most marginalised part of the population, common business models will only work if a large number of users can be expected, or if third parties pay for the service. If SMEs are the clients, then various business models are feasible as long as the SmartTech solution creates positive effects that improve revenues. In any case, both sides must be considered in the search for a suitable business model: the customer as well as the service/solution provider. Typically, e-commerce, access to finance and insurance, market linkage, and machinery pooling are e-agricultural use cases where sustainable business models can be most easily found.
- **Find and create synergies**. The promotion of financial services and the related improvement of financial literacy in rural areas can benefit from the introduction of ICTs, and vice versa. Likewise, local IT firms will benefit from investments in ICT. More sustainable livelihoods in rural areas will allow public and private investments in the infrastructure of these regions, as the communities will be able to pay for the services. A contract farming scheme with thousands of producers might be of interest to financial service providers as a source of customers.

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