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Moving towards a green productive agriculture in Africa: The role of ICTs

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Abstract

Agriculture remains an important source of livelihood for the majority of Africans but the sector is still very unproductive, resulting in food insecurity and large imports of staple foods, putting additional strain on scarce foreign exchange reserves. Acknowledging the rapid uptake of Information and Communication Technologies (ICTs) in Africa and building upon the mitigated success of the green revolution in Asia, the paper discusses the potential of ICTs to transform Africa's agriculture in an inclusive and sustainable way, by benefitting smallholders, addressing land reform issues, providing adequate financial services, price and market information as well as by boosting global value chains. The study goes further by providing policy recommendations for African governments and the private sector on how ICTs usage could be further leveraged to enhance productivity and promote a green agriculture in Africa.

1 | Introduction

Despite the importance of the agriculture sector in Africa, its productivity considerably lags other developing regions. Africa has the highest area of arable uncultivated land (202 million hectares) in the world but countries have not yet taken advantage of it. Food production, transformation, and consump - tion systems are not functioning optimally. In consequence, the continent has the highest incidence of undernourishment, estimated at almost one in four persons (World Food Programme, online), and African countries import increasingly more agricultural prod- ucts than they export, putting additional strain on scarce foreign exchange reserves. While Asia's green revolution[2] mainly focus- ed on irrigated wheat and rice together with improved crop varieties and expanded use

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[2] Starting from the 1960s' over the World and specifically in Asia, the green revolution refers to the drastic rise in agriculture productivity as a result of chemical advances and the development of high-yield crops, thus making it possible to produce much larger quantities of food (WEF et al., 2015).

of chemical fertilizers, Africa's soils vary by region and need a more tailored approach (Nin-Pratt and McBride, 2014; World Bank, 2008). Africa's low use of irrigation and overwhelming dependence on often insufficient rain-fed agriculture also hinder the continent's low agricultural productivity. As a matter of fact, Malawi which has efficiently managed its available water supply since the launch of the Green Belt Initiative in 2012 (Grow Africa Secretariat, 2014), became the second top food crops producer in Africa in 2013 (World Bank, online). Limited funding in the agriculture sector by African governments and development partners has also prevented the provision of adequate institutional support and suitable business environment, in turn hindering private sector participation and investment in agriculture (WEF et al., 2015; Voortman, 2013). For instance, Rwanda which is endowed with a good business environment (62nd out of 189 countries according to the World Bank's Doing Business Report 2016) has witnessed increasing private investments in its agriculture sector amounting $512 million between 2000 and 2013 as well as growing diversification in agricultural sub-sectors with promising growth potential like beverages and horticulture (Grow Africa Secretariat, 2014).

Increasing agriculture productivity in Africa would support structural transformation process and economic diversification as reliance on subsistence production and weak productivity growth in the agriculture sector prevents the workforce from moving out of this sector into manufacturing and services (Bah, 2011 and Herrendorf et al., 2014). It is also expected to promote inclusive growth, especially given that the sector provides employment to half of the labor force, including to a high percentage of smallholder farmers (representing 80 percent of total farmers) and female workers (AfDB, 2014a). A substantial body of the literature finds that agriculture-led growth has greater impact on poverty and inequality reduction than growth driven by other sectors (Thirtle et al., 2003; Salami et al., 2010). Furthermore, building upon the mitigated success of the green revolution in Asia, African countries need to ensure that agricultural productivity be raised in a sustainable way (WEF et al., 2015). Indeed, although Asian countries doubled cereal production between 1970 and 1995 while the total land area cultivated with cereals increased by only 4 percent (World Bank, 2008), this success has been lessened in the long run by the increasing dependence and poor management in the use of agrochemicals. According to Lappé et al. (1998), misused of agrochemicals has resulted in adverse environmental consequences, including on water supply, soil quality and greenhouse gas emissions, as well as subsequent stagnation in crop production and rising cost of agricultural inputs. The adverse effect of the green revolution on the environment in Asia eventually led a large number of smallholder Asian farmers ending up indebted, landless and poor (Lappé et al., 1998).

Taking into account these challenges, the paper discusses the potential of Information and Communication Technologies as a tool to transform Africa's agriculture in a sustainable way and provides recommendations not only to enhance agriculture productivity but also to promote a green agriculture in Africa. The next section gives an overview of the rapid uptake of ICTs in Africa. Section 3 analyzes the multiple ways ICTs can transform agriculture and benefit smallholders, by addressing land reform issues, providing adequate financial services, price and market information as well as by boosting global value chains in the agriculture sector. Section 4 provides some policy recommendations and the last section concludes.

2 | The rapid uptake of ICTs in Africa

The ICTs are a heterogeneous set of goods and services used to produce, process, distribute and transform information. The empirical literature acknowledges the benefits of ICTs on economic growth. In various countries, studies have demonstrated that investment in ICTs, be it in Internet, mobile telephone or fixed-line broadband penetration, positively correlates with Gross Domestic Product (The Boston Consulting Group, 2009; Fuss et al., 2005; Qiang and Rossotto, 2009). Returns on ICTs investment also include increased competitiveness and trade, private sector development, innovation and job creation (Katz et al., 2009) as well as poverty reduction (Adera, 2014). Indeed, ICTs act as a multiplier for connecting people and places, improving supply chains, collaboration and financial transactions while making pricing more dynamic and processes more transparent. It unlocks new efficiencies and capabilities in various economic sectors, including in education, e-governance, finance and healthcare (World Economic Forum, 2009). Regarding women empowerment, ICTs in agriculture could help women save time, physical effort and have access to finance in addition to supporting the monitoring of equal access to agriculture programs. ICTs are a valued tool, especially in rural areas, to expand money transfer services and governments should ensure that these services be accessible to women (Van Zyl et al., 2012).

Technologies with low infrastructure requirements and low costs like radio continue to be the most used on the continent, including when compared to other traditional mass medium like television, newspapers and broadband fixed lines (see Table 1).

However Geographic information systems (GIS), satellite imagery technologies, Internet and mobile telephony are expanding in Africa (Balancing Act, 2008) despite many obstacles such as infrastructure, affordability, computer literacy and language skills (International Telecommunication Union, 2003). For instance, African countries still lack good GSM networks and electrification infrastructure, especially in rural areas (Torero, 2014). Furthermore, literacy still is at a low rate of 59.3 per cent of Sub-Saharan people aged 15 and above in 2010 (World Bank, online) and this constitutes a crucial obstacle to access and exchange information through technology (Adomi, 2011). Africa also has the lowest rate of Internet usage in the world, although the latter has been on the rise throughout the continent, with an annual growth rate going from 0.5 percent in 2000 to 16.9 percent in 2013 (see Figure 1).

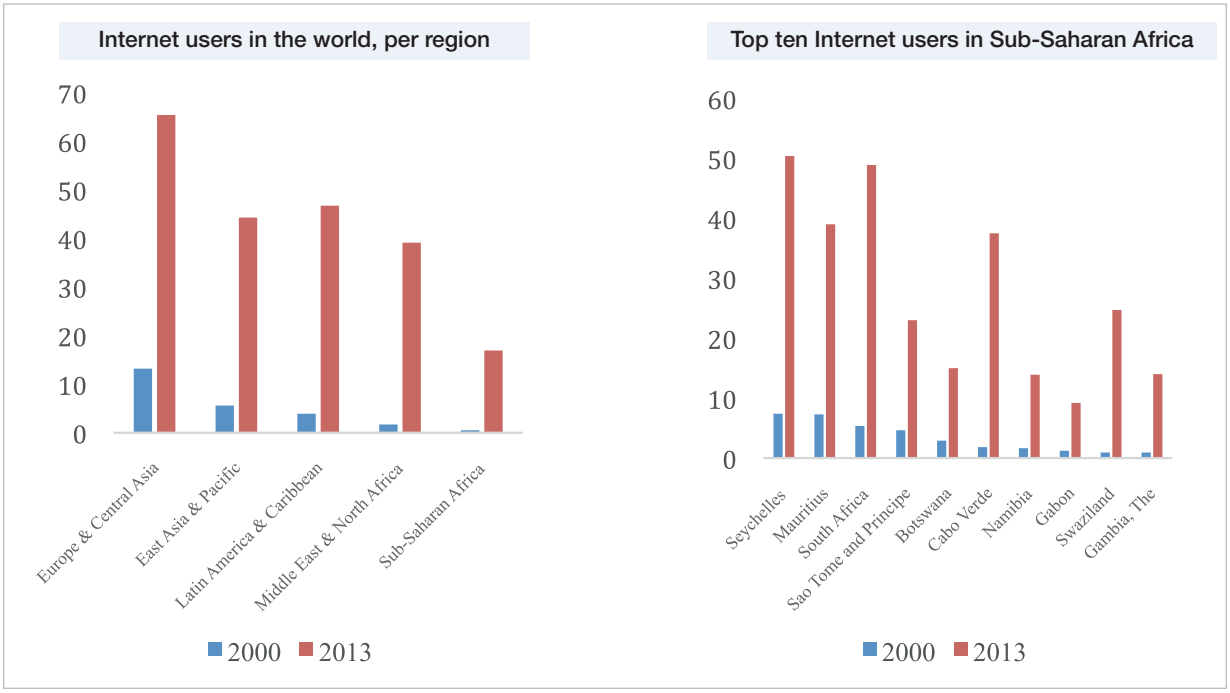
Mobile Internet broadband presents great potential as the number of cellular subscriptions has grown exponentially between 2000 and 2013 in Africa (see Figure 2). By contrast, fixed broadband subscriptions have remained very low in Sub-Saharan Africa, at 0.3 per 100 people in 2013 (World Bank, online).

Table 1 Proportion of households with selected ICT medium for selected years and sub-Saharan African countries

	Proportion of households with											
	Radio	Year of data	TV	Year of data	Fixed line tele-phone	Year of data	Mobile-cellular tele-phone	Year of data	Compu-ter	Year of data	Internet access at home	Year of data
Congo (Rep.)	54.3	2011	46.8	2011	...		81.0	2011	4.0	2011	1.0	2011
Lesotho	61.1	2011	22.6	2011	3.5	2011	72.0	2011	4.8	2011	2.6	2011
Malawi	45.6	2011	8.7	2011	0.8	2011	36.3	2011	4.0	2012	5.5	2012
Mali	63.0	2015	32.2	2015	1.5	2015	82.7	2015	3.3	2015	8.2	2015
South Africa	56.7	2014	80.9	2014	12.7	2014	91.9	2014	20.8	2014	44.2	2014
Tanzania	65.0	2011	15.0	2011	...		...		...		...	
Zimbabwe	37.9	2011	36.3	2011	4.1	2011	62.2	2011	10.7	2014	4.8	2011

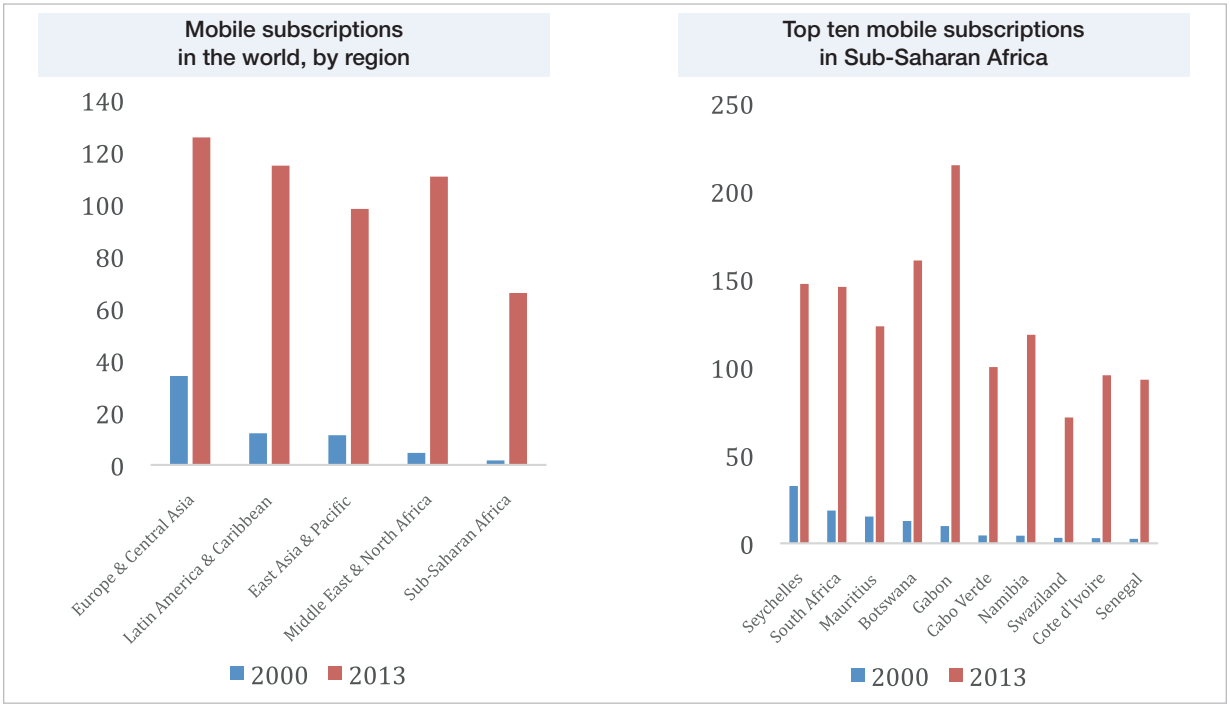
Source: Authors, based on International Telecommunication Union (ITU, online).

Figure 1 Internet users in 2000 and 2013 (per 100 people)



Source: Authors, based on the World Bank (online).

Figure 2 Mobile cellular subscriptions in 2000 and 2013 (per 100 people)



Source: Authors, based on the World Bank (online).

The rapid uptake of new media in Africa, particularly Internet and mobile telephony but also progressively GIS and satellite imagery technologies, provides an important opportunity to improve agricultural sector performance from the farm to the market. These new technologies could play a key role in supporting land reforms as well as in providing price and market information that is crucial to foster greater integration into agricultural value chains. Several potential avenues on the ways to leverage ICTs for improved agricultural productivity are available at both crop pre-cultivation and post-harvest stages as highlighted in Table 2 (entitled "Successful new ICT-based services in the agriculture sector in Africa").

The following section looks at various new ICT applications increasingly used in the agriculture sector in Africa, specifically for land reform, market information and value chains, highlighting successes. It also considers the opportunity that these technologies offer to move towards a green agriculture sector.

3 | Leveraging ICTs to transform agriculture

3.1 Supporting land reform and leveraging farmers' assets at the pre-cultivation stage

When land governance and ownership are based on customary laws, they often lead to unequal distribution of land and uncertainty of tenure (WEF et al., 2015). By contrast, land reforms that clearly define property rights, ensure the security of land tenure, and enable land to be used as collateral and to be allocated efficiently, is as a pathway to shared prosperity in Africa (Byamugisha, 2013).

GIS, Remote Sensing (RS) and satellite imagery technologies can be very useful at the pre-cultivation stage with regards to land selection by facilitating the process of land registration and allocation (WEF et al., 2015). ICT can enable and complement the reforms aimed at enhancing tenure security for farmers to leverage their assets. GIS and Remote Sensing[3] (RS), whose costs have been declining since the 1980s together with the proliferation of low-cost software and microprocessor developments, are increasingly being used to ensure more efficient land use and water management. For instance, some countries such as Cameroon are using GIS systems to first register land before implementing redistribution mechanisms (WEF et al., 2015). GIS combined with RS has been used to support the assessment of land capability, soil conditions, crop condition and yield, flood and drought risk, groundwater contamination, and pest infestation (Wilson, 2005). For example, Egypt has developed a soil and terrain database for the Sinai Peninsula and other regions (WEF et al., 2015). Satellite imagery data and GIS have also been used in Ethiopia and Mozambique to enable land registration and crop inventories (Deloitte, 2012).

[3] Remote sensing is the use of aerial sensor technologies to detect and classify objects on Earth with the help of propagated signals such as electromagnetic radiation (Panigrahi, 2014).

Table 2 Successful new ICT-based services in the agriculture sector in Africa

Stage	Action points	Champion countries
Pre-cultivation stage	Leverage GIS, Remote Sensing (RS) and satellite imagery technologies to enhance land tenure security for farmers (land registration, crop inventories)	Cameroon, Egypt, Ethiopia Mozambique
	Use mobile phone as a payment tool for crop insurance and credit in the agriculture sector	Kenya (Kilimo Salama, using M-PESA)
	Build a virtual common information system platform (through mobile phone) linking all stakeholders in the agriculture sector, comprising a database containing farmers' information	Kenya (M-Kilimo)
	Provide information through mobile phones on crop cultivation, best agriculture management practices and market prices to enhance agriculture production and productivity in a sustainable way and increase farmers' income	Kenya (Agri VAS), Mali (Agri VAS) Tanzania (Agri VAS), Ghana (Agri VAS) Côte d'Ivoire (Agri VAS)
Post-harvest stage	Use mobile phones in commodity exchange to disseminate information on market prices and knowledge data on products as well as facilitate coordination and contract enforcement between buyers and sellers	Ghana (E-Soko) Ethiopia (Ethiopia Commodity Exchange)
	Provide quality and traceability information on products through mobile phones to improve integration into global agriculture value chains	Kenya (iCow, Syngenta)

Mobile phones can also be very useful at the pre-cultivation stage with regards to crop selection as well as for taking inventory and obtaining weather information on the planting calendar. It can generate valuable information on land preparation and sowing, crop health, input management—particularly the choice and use of fertilizer—and pest and water management (WEF et al., 2015), thereby increasing productivity and production while decreasing maintenance costs. Researchers can also contribute to these platforms, adopting more easily agricultural best practices and disseminating them to farmers (Chavula, 2014). In 2011, the GSMA Magri Programme, in partnership with the Bill & Melinda Gates Foundation, launched the mFarmer initiative to support the development of mobile agricultural value-added services (Agri VAS) in four countries: India, Kenya, Mali, and Tanzania. The Agri VAS, developed by mobile network operators, is designed to offer information on crop cultivation and market prices to farmers (Jadhav et al., 2011). In the same vein, CocoaLink, which is a public-private partnership between the World Cocoa Foundation and Orange, provides farmers in West Africa with information on good agricultural and management practices on cocoa production through mobile technology. The program represented 3,700 users in Ghana at the end of 2013 (United Nations, 2014) and targets to reach 100,000 cocoa farmers in Côte d'Ivoire, knowing that over one million Ivoirians are engaged in the production of cocoa (Grow Africa Secretariat, 2014). Other information system platforms linking all stakeholders include Kenya's M-Kilimo, which comprises a database containing farmers' information (land size, crop, language, etc.) (WEF et al., 2015). Farmers can call to report problems and ask questions. Specific responses are tailored to the farmer whose information is already available in the system.

At the pre-cultivation stage, mobile phones can also support the development of crop financial and insurance products. So far, the financial and insurance sectors has not developed farmers-friendly policy, thereby hampering farmers' access to these services (WEF et al., 2015). Progress in this regard would significantly facilitate the development of the agricultural sector as crops are vulnerable to weather and climate change. M-PESA in Kenya is a well-known example of a mobile technology–based transfer service with multiple usage patterns that has increased financial inclusion, notably in rural areas (WEF et al., 2015). Mobile phones are used to scan the barcode of products purchased by farmers and M-PESA is used for the payout. Farmers can also use M-PESA to save and borrow small amount of money, thereby mitigating the risks of bad weather and subsequent poor harvest when they buy input. The insurance Kilimo Salama[4] (which means agriculture without risk in Swahili) is a mobile technology–based insurance on purchased inputs (certified seed, fertilizer, and crop protection products) that protects farmers against bad weather shocks. The insurance uses M-PESA for all transfer payments (WEF et al., 2015).

3.2 Providing price and market information at the post-harvest stage

Market information is crucial to improving agricultural market efficiency. A lack of sufficient information—notably on prices and market conditions—along with price information asymmetries make it difficult for farmers to get fair prices for their crops. These asymmetries extend beyond the local market into regional and global markets and uncertainty can also discourage investments

[4] https://kilimosalama.wordpress.com/

in inputs and technologies (WEF et al., 2015). Mobile phones are used to improve the marketing of agricultural products into regional and global markets, while at the same time being used to receive market information in a timely manner by reducing information asymmetry and market information throughout the different phases of the production process as well as in the post-harvest period (World Bank, 2011). They are also used to get information to farmers, particularly smallholder farmers in remote areas who could otherwise be out of reach. Agrinet, for instance, is a platform collecting and disseminating market intelligence as well as brokerage service in the agriculture sector in Uganda, using both SMS and physical information boards strategically located in agriculture markets (World Bank et al., 2012).

Efforts are also being made on the continent to deal with information generation and dissemination issues through mobile phones within the context of commodity exchanges. For example, the E-Soko (which means electronic market in Swahili) Ghana commodity exchange[5] (EGCI), operational has published a weekly cash price index of commodities since 2005 (WEF et al., 2015). E-Soko has expanded in a dozen countries and provides price and knowledge data to farmers via mobile text messages. Among other things, this application prevents farmers to pass through intermediaries and their arbitrary prices (United Nations, 2014). An even better known commodity market is the Ethiopia Commodity Exchange (ECX), which addresses the huge market inefficiency that prevented commodity buyers from interacting directly with sellers, and vice versa. The ECX disseminates information on products' grades and prices and facilitates the coordination of buyers and sellers as well as the enforcement of contracts. All farmers in the country, including smallholder farmer cooperatives representing 2.4 million of farmers, are members of the ECX. Information which is provided through a call center addresses the asymmetry issue about the prices of crops in different markets. Farmers who have had more marketing options and more bargaining power, increased their income by 10 to 30 percent (Adewunmi, 2012).

3.2 Enhancing Agricultural Value Chains

Increased globalization has created new challenges and opportunities for Africa's agriculture including the continent's greater integration into Agricultural Value Chains (AVCs). For African farmers to take advantage of large markets, they need to deliver high-quality products at competitive prices and integrate international distribution channels by satisfying the norms and standards set out by their trading partners (AfDB et al., 2014). This is a serious challenge for smallholder farmers, who supply up to 80 percent of the food in sub-Saharan Africa (FAO, 2012) but need to enhance their capacity to meet international standards.

Greater integration into AVCs is expected to boost benefits to small-scale farmers and facilitate the creation of agribusinesses for increased value addition in exported goods. Participation in AVCs facilitates access to inputs, financing, and end-markets at different levels, thereby enhancing economic returns (UNECA, 2013). This, in turn, facilitates the creation of modern integrated agribusiness value chain economies based on specialization (AfDB, 2014a). AVCs trigger knowledge and technology transfer as well as economies of scale, thereby enabling firms to "move up" into higher-value activities, capture a greater share of value in global markets, and thus enhance the sector's competitiveness (Gereffi et al. 2005, cited in AfDB et al. 2014).

The rapid uptake of Internet in Africa provides an important opportunity to improve the performance of AVCs from the farm to the market by strengthening synergies between the diverse stakeholders along the agricultural value chains and facilitating traceability. Ultimately, the integration of agriculture projects into a long-term integrated hub would facilitate the coordination of big agriculture projects, support the development of agricultural value chains, create new opportunities including economic and export diversification and bring economies of scale in the sector (Van Zyl et al., 2012). An example of the use of Internet to improve integration into global value chains is the traceability of food and animals. Traceability entails displaying the lot number and the production facility name on each case of the product and recording this information on invoices and bills of lading. Data can be recorded and transmitted via different Web-based applications (World Bank, 2011). In 2011, the Swiss Foundation Syngenta created a software to stock and manage online data for Kenyan farmers, providing information on the pesticide content in the fruits and vegetables produced before they are exported. This application also supports farmers in their aim to meet the quality standards and traceability requirements at the global level (United Nations, 2014). Similarly, an application that monitors cattle and provides valuable information, called iCow, was launched in Kenya (WEF et al., 2015).

3.4 ICT and green growth in agriculture

Building upon the definition of green growth[6], agricultural development should not lock countries into pathways that deplete

[5] See http://www.esoko.com/
[6] The African Development Bank defines green growth as "the promotion and maximization of opportunities from economic growth through building resilience, managing natural assets efficiently and sustainably, including enhancing agricultural productivity, and promoting sustainable infrastructure" (AfDB, 2014b).

their natural resources and leave their economy and livelihoods more vulnerable to climate change, threatening economic growth and human well-being over time. By contrast, ICTs not only have the potential to enhance agricultural productivity in Africa, but they can also do so in a way that advances a "green" agriculture in the continent. They can provide the tools to manage natural resources and reduce environmental risks while contributing to sustainable agricultural development in Africa. Remote sensing and satellite imagery applied to insurance companies operating in the agriculture can mitigate the risks against weather adversity and climate change and convince operators to invest more in farming activities, which in turn will protect the livelihoods of individual farmers (World Bank and FAO, 2012).

Furthermore, studies show that farmers lack appropriate knowledge on inputs and, as a result, do not use the appropriate quantity and type of fertilizer, thereby increasing production costs and harming human health and the environment (World Bank and FAO, 2012). The e-Krishok program in Bangladesh created an online tool, the Fertilizer Recommendation Solution (FRS), which informs farmers on the right quantity and chemical type to be used for a specific crop and location (World Bank and FAO, 2012).

Radio as well as mobile technology through SMS or Multi-media messages which allow for pictures combined with Internet allow for the diffusion of information to large parts of the population, including those located in remote areas. These can serve as a means to reduce travel required for information collection given that the farmers themselves are collecting and sharing the data in a timely manner via mobile applications. They can transform complex data into easy-to-use messages tailored to particular contexts and circumvent literacy issues, thereby providing operational information in a cost-effective way to smallholders. This method of sharing information, while being inclusive, thus minimizes in a significant way the emission of greenhouse gas. They are constantly evolving and new opportunities to leverage these technologies in the agriculture sector are increasing day after day.

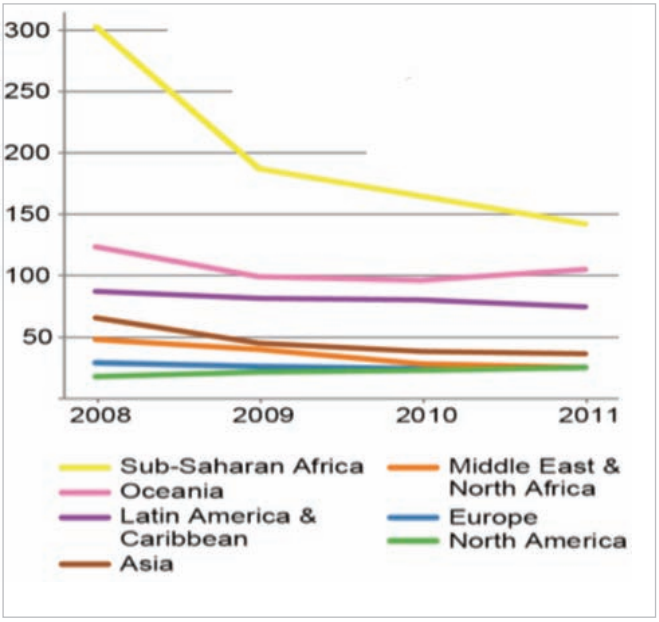
4 | Policy recommendations for developing ICTs across African countries and leveraging their use in the agriculture sector

In order to leverage ICT for agricultural productivity across the continent in an inclusive and environment-friendly way, reliable and affordable, ICT infrastructure needs to be developed. The legislation and regulations related to ICTs would need to ensure that the cost of ICT infrastructure (e.g. broadband) is reduced and that ICT infrastructure is accessible to all, even those located in remote areas. Since the 1990s, telecommunication networks have grown significantly in Africa. Taking the example of mobile networks, they now cover 90 percent of the continent's urban population but only half of its rural population. Furthermore, mobile network coverage development has been slowing recently because it is not commercially viable in some parts of rural areas where the population is extremely thinly distributed (Williams et al., 2011). As a matter of fact, due to infrastructure constraints, agricultural production in Africa still benefit more from telephone main lines (Chavula, 2014). However, the rapid uptake of new ICTs in Africa, especially mobile phones and Internet but also GIS and satellite imagery technologies, is being increasingly leveraged in the agriculture sector and offers great promise of enhancing agriculture productivity in Africa in a sustainable and "green" way, as discussed in section 3. To expand and facilitate the use of ICTs by the private sector and other stakeholders in the agriculture sector as well as end-consumers, further efforts are needed to enhance the efficient delivery, accessibility and use of ICTs across the continent. The public sector should consider the option of providing subsidy or adopting Public Private Partnerships (PPP) to ensure mobile coverage in remote areas. Williams et al. (2011) conducted a spatial analysis of the costs and benefits of universal mobile network coverage across Africa. Thanks to the recent developments in GIS technology, authors estimated that 92 percent of Sub-Saharan Africa could have a commercially viable mobile network coverage. In the remaining, unprofitable 8 percent of the continent, only USD 1 billion per year over nine years is required to expand mobile network coverage. Authors also indicated that the cost of providing universal mobile coverage is unequal among countries as it depends on population density in rural areas. Democratic Republic of Congo, Madagascar and Zambia, for instance, have more unprofitable areas and thus face more financial needs than other African countries to achieve universal mobile coverage. The African governments would need to support private companies to achieve full ICT coverage by providing direct financial subsidies or taxes reduction on equipment and services in rural areas. In Afghanistan and India, the national authorities provided direct subsidy targeting shared infrastructure and allowed its use by multiple operators, thereby encouraging competition in the ICT sector and ultimately expanding networks in rural areas (South Asian Telecommunications Regulator's Council, 2012). Removing regulatory restriction on the provision of value added services via ICT networks would raise additional revenues. In Kenya, for instance, the launch of the M-PESA banking service has led to a rise in ICT use in rural areas, thus increasing the sector profitability and the incentives to expand the network in remote areas (Williams et al., 2011).

In the same vein, although broadband Internet is expanding in Africa, its network coverage is still limited and its price is out-of-

reach for the majority of Africans. Figure 3 indicates that the cost of broadband subscription for one month has decreased in Sub-Saharan Africa but it is on average higher than in any other region worldwide.

Figure 3 Cost of one month of broadband subscription per region in 2008-2011, in USD



Source: Graham and De Sabbata (2014) based on data from ITU and the World Bank.

However, Internet access is becoming easier and cheaper over time thanks to the development of fiber-optic networks and even more significantly to technological innovations in wireless network infrastructure. A universal Internet coverage based on a low penetration and shared access scenario would require an additional USD 648 million per year over eight years (Williams et al., 2011).

The ICT market liberalization should be completed such as to avoid monopoly and encourage competition between private operators. Some African countries still prohibit competition among ICT operators (such as Comoros, Ethiopia, Sao Tome and Principe as well as Swaziland for the mobile market) while others have passed legislation but have not implemented it (Eritrea, for example, has not issued additional licenses in the mobile market). By contrast, Nigeria which has been a pioneer in the liberalization of the fixed-line market in the region, now provides quality services at good price to costumers. Overall, it has attracted 60 percent of the telecommunication investment in Sub-Saharan Africa, together with South Africa (Williams et al., 2011).

Promoting knowledge would also enable people to efficiently use ICTs in agriculture. Indeed, the end user will benefit from the technology only if it is available, easy to use, reliable and cheap (Van Zyl et al., 2012). As a matter of fact, Sub-Saharan African countries should not only encourage education but also invest in higher education and research related to technological capacity in order to support the innovation and dissemination of new technologies and technological techniques (Chavula, 2014). This would, among others, encourage ICT systems' designers and developers to design new technology and apply them to ICT-based agriculture services which are commonly available and used in the region. Some ICT services such as Agri VAS, CocoaLink and M-Lilimo provide farmers with technology innovation on mobile devices that overcome the illiteracy obstacle and optimize information sharing. Esoko and the Grameen Foundation offer agriculture advisory services in Africa, notably by voice message. Similarly to M-Kilimo, they have also established live call centers of agricultural experts to provide local farmers with customized solutions (World Bank et al., 2012). In the same vein, Lifeline India has established an interactive voice response focusing on the agriculture sector with about 10 percent of the calls receiving automatic answers (World Bank et al., 2012). Talking Book which is an ICT designed providing information on agricultural technologies in local language to illiterate farmers using audio computer is another success story. According to a pilot study conducted in a rural village in Ghana in 2009, households using Talking Books on an intermittent basis grew 48 percent more food than other households (World Bank et al., 2012).

These ICT-based advisory services in agriculture in Africa are essentially supported by donors and international organizations and the public sector also contributes to the uptake. However, sustainable private sector business models are also being developed. Esoko raises revenues by selling subscriptions to its platform to farmers, agribusiness, the government and Non-Government Organizations (NGOs) and by charging fees on its SMS, consulting and training services (World Bank et al., 2012). At the post-harvest stage, Agrinet in Uganda is an attractive business model as it successfully relies on its market intelligence to offer brokerage services and earn commissions for its broker deals (World Bank et al., 2012). African governments should further encourage private-sector development in ICTs to ensure the sustainability of the latter in the agriculture sector, through a regulatory framework which is favorable to private sector innovation, entrepreneurship and investment, the provision of sufficient, efficient and cost-saving telecommunications infra-structure as well as incentives and skills for end-consumers to use ICTs effectively. Furthermore, public-private partnerships are also potential viable business models. The mFarmer program, for example, has shown interest and conducted a study on the Indian Farmers Fertilizer Cooperative (IFFCO) Kisan Sanchar

limited (IKLS), a partnership between IFFCO which is the largest farmer cooperative in India, and Airtel, a mobile network operator in the same country (World Bank et al., 2012).

Broadly speaking, governments have the responsibility to reduce the regulatory barriers for private operators to launch and improve those multiple ICT services that impact farmers' income and productivity in a sustainable way. They also have a key role to play in promoting knowledge on the use of ICT services in agriculture through training, advertisement and raising awareness campaigns, for the agriculture and other relevant stakeholders to be aware of the potential opportunities of these technologies for agriculture competitiveness and environmental benefits. African governments could also facilitate partnerships not only between (small and large-scale) farmers and other professionals from the sector but also by creating networks across sectors, with scientists in the academia as well as the banking and insurance sector for example. Ultimately, African governments could support the establishment of a common platform with centralized collection and monitoring of consistent data by the various relevant stakeholders through ICTs, at the national and regional levels. This would avoid duplication of data, encourage an efficient division of labor between stakeholders using the ICTs and eventually allow ICT-users in the agriculture sector to save costs in data gathering and monitoring, while triggering knowledge sharing on production and marketing and eventually enhance agriculture productivity and sustainability.

5 | Concluding remarks

Agriculture remains an important source of livelihood for the majority of Africans but the sector is still very unproductive, resulting in food insecurity and large imports of staple foods. Insufficient investment in agriculture as well as poor land governance have contributed to Africa's low agricultural productivity.

By contrast, the use of ICTs would lead to a more competitive and inclusive agriculture sector as well as a faster structural transfor - mation process across the African continent. Overall, ICTs facilitate land registration and allocation, thereby supporting land reforms. ICTs also help develop financial instruments suited to the agricultural production cycle and facilitate farmers' access to credit and insurance products for crop. By helping farmers, including those located in remote areas, to improve their production and marketing processes, ICTs provide them with more opportunities to meet the high-quality standards in global world markets, which in turn make them adopt better production processes and garner higher prices for their products. Diffusion of market information and production knowledge have been increasingly used in Africa but ICTs usage could be further enhanced.

ICT applied to farming activities is also a step towards a "green" agriculture, since it goes beyond boosting agriculture productivity. It enables both the delivery of environmental benefits and the reduction of greenhouse gas emissions during farming activities, and reduces the risks related to climate change and environmental shocks for both farmers and insurance companies operating in the agriculture sector. By leveraging ICTs, Africa's agriculture will improve along with these new technologies and may eventually reach green and inclusive growth faster than other developing regions.

ICTs in agriculture would facilitate the communication between the various stakeholders along the agricultural value chains and the coordination of big agricultural projects likely to bring economies of scale in the production, export diversification and job creation. African governments have a key role in supporting ICT development to leverage the full potential of telecommunication in the agriculture sector through adequate policy. They would also need to leverage the potential of the private sector together with donors to establish sustainable business models of ICT-based agriculture services. Particular efforts should be directed towards the provision of ICT infrastructure in rural areas. The benefits of ICTs for the agriculture sector would also be optimized if the government supports innovative ICTs which are reliable, affordable and easy to use for illiterate or low-skilled farmers. More broadly, governments could disseminate knowledge on the potential benefits of ICTs in the agriculture sector as well as facilitate partnerships between the various stakeholders to encourage them in further leveraging communication technologies to enhance the competitiveness and sustainability of the agriculture sector.

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