Paving the way towards digitalising agriculture in South Africa

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Executive summary

The application of advanced technologies such as machine learning (ML), artificial intelligence (AI) computer vision, remote sensing, unmanned aerial vehicles (UAVs), and the Internet of Things (IoT) has the potential to transform the agricultural sector under the right enabling conditions. The application of these technologies is part of a broader digital transformation that is occurring globally and is increasingly manifest in the agriculture sector. The digitalisation of agriculture is defined by the conversion of measurements of agricultural inputs and outputs into digitally stored data for use in automated systems and applications that provide information and assist decision-making. Hence, this transformation unveils an array of opportunities that may help to address South Africa's food security challenges, create jobs, and address historical inequalities. There are also risks involved in the digitalisation of agriculture. These include the potential for digitalisation to cause job losses, further marginalise African countries in the global supply chain as well as increase or create new inequalities.

This analysis demonstrates that in South Africa, there is a need for the government and policymakers to look into the agriculture sector as part of the entire value chain; as a measure to mitigate the challenges such as the risks associated to employment, data governance and access to finance. The findings also highlight the importance of increasing digital inclusion amongst farmers as a measure to increase their visibility in the wider value chain ecosystem; improving on the physical infrastructure directly related to the sector (road, water, power); and introducing policy frameworks that address open data, data protection and governance. It is also important for government to promote an environment for public-private interplays (PPIs) as well as a landscape for large scale commercial farmers to support small-holder farmers, as it can aid in supporting the development of small-scale subsistence farmers into small commercial farmers. In addition, the role of PPIs and commercial farmers is a cross-cutting issue that needs to be integrated at all levels of agriculture development for the wellbeing of the agriculture sector as a whole, including emerging and small-scale farmers. The policy recommendations arising from this research are to:

- develop policies that encourage the uptake of appropriate technology within the agriculture sector while also addressing the emerging challenges regarding data protection, data ownership and governance;
- create educational programmes to provide the youth with the skills to address the changing needs of the agriculture sector, while at the same time demonstrating awareness of entrepreneurship career opportunities that are emerging along the entire value chain;
- encourage the development of platforms to encourage commercial farmers to engage in knowledge transfer and the up-skilling of small-scale farmers, to ensure they are not left behind in the digitalisation of the sector;
- ensure a more equitable and inclusive mechanisation of the agricultural sector by encouraging the sharing of equipment (such as tractors) as a way to provide logistical support for small-holder farmers to gain efficient access to the market and the wider value chain;
- work with the private sector to strengthen digital infrastructure to ensure constant and reliable internet connectivity in rural areas while enacting regulation that makes data and smartphone devices more accessible for small-holder farmers and poorer communities;
- respond to water and power shortages by promoting innovative and sustainable practices, especially amongst small-holder farmers; and

- improve access to finance for small-scale and emerging farmers by fuelling more funding, engaging with the formal financial sector and harnessing the benefits of alternative finance solutions such as microfinance and crowdfunding, while also creating funding opportunities for local entrepreneurs.

Glossary

4IR - 4th Industrial Revolution

ADA - Agribusiness Development Agency

AfDB - African Development Bank

AGDA - Agricultural Development Agency

AI - Artificial intelligence

AU - African Union

CoCA - Census of Commercial Agriculture

CSI - Committee for Spatial Information

DAFF - Department of Agriculture, Forestry and Fisheries

DALRRD - Department of Agriculture, Land Reform and Rural Development

DRDLR - Department of Rural Development and Land Reform

ECSECC - Eastern Cape Socio Economic Consultative Council

EU - European Union

FAO - Food and Agriculture Organization of the United Nations

GDP - Gross domestic product

GDPR - General Data Protection Regulation

GIS - Geographic information system

GODAN - Global Open Data for Agriculture and Nutrition

ICT - Information and communications technology

IoT - Internet of Things

LRAD - Land Redistribution for Agricultural Development

ML - Machine learning

MNO - Mobile network operator

NDP - National Development Plan

NEPAD - New Partnership for Africa's Development

OECD - Organisation for Economic Co-operation and Development

PII - Personally identifiable information

POPI - Protection of Personal Information Act

PPI - Public-private interplay

PPP - Public-private partnership

QLFS - Quarterly Labour Force Survey

RAMP - RIA's African Mobile Pricing (RAMP) Index

RDI - Research, Development, and Innovation

RIA - Research ICT Africa

SAAFoST - South African Association for Food Science & Technology

SASDI - South African Spatial Data Infrastructure

SMMEs - Small, medium, and micro enterprises

Stats SA – Statistics South Africa

UAVs - Unmanned aerial vehicles

USSD - Unstructured Supplementary Service Data

WCDoA - Western Cape Department of Agriculture

Paving the way towards digitalising agriculture in South Africa

1. Introduction

The Food and Agriculture Organization of the United Nations (FAO), estimates the world's population will increase by 2 billion by 2050 and during this time land under cultivation will only increase by 4% (Dharmaraj & Vijayanand, 2018). Driving sustainable agricultural practices and the development of rural areas is equally important to eradicate extreme poverty and hunger in South Africa and the rest of the African continent. With an estimated 20% (Stats SA, 2019a) to 50% (Oxford, 2018) of the South African population being food insecure,[1] food insecurity will become an increasingly urgent challenge.

As of Q4-2019, the agriculture sector employed 885,000 people in South Africa. Due to droughts, the sector did not perform well. However, the sector has the potential to contribute at least 3% towards gross domestic product (GDP), which was the figure in Q3-2017 prior to the droughts. Despite its small contribution towards GDP, agriculture is of great economic importance in South Africa and the primary sector in rural areas (Deloitte, 2012). It is a significant provider of employment and a major earner of foreign currency. Furthermore, "close to 8.5 million people are directly or indirectly dependent on the industry for their employment and income" (Tennant, 2018).

South Africa's agriculture sector comprises of 35,000 registered commercial farmers, 40% of which are engaged in field crop farming, with 60% focused on livestock farming (Gillwald et al., 2019). There are 4 million small-holder farmers in South Africa that are comprised almost entirely of the native black population farming mainly in former homeland areas[2] on 13% of agricultural land. In contrast, there are 35,000 white farmers (mainly large scale farmers) producing approximately 95% of agricultural output on 87% of agricultural land (Pienaar & Traub, 2015).

With that, small-holder farmers are the ones that struggle most to benefit from opportunities that the agriculture sector presents, such as increased demand for food due to the increase in the population. And although they play an important role in the sector, they still struggle because of unsustainable farming practices, poor infrastructure and logistics, shortage of farming skills and resultant soil degradation. In addition, the current slow growth in the economy along with high costs of power and agriculture inputs, water scarcity and limited access to market and financial credit, are some of the added reasons that are limiting the growth of small-scale farmers' productivity and growth in South Africa (Matlou, n.d.).

In a report by Comins in 2015, the Director of the Centre of Excellence in Food Security at the University of the Western Cape, Professor Julian May told hundreds of delegates at the South African Association for Food Science & Technology's (SAAFoST) biennial conference that although food security was a constitutional right and that progress had been made in poverty alleviation, the country faced "considerable risk" of food insecurity. Data from Statistics South Africa (Stats SA) shows that 21% of citizens were "food insecure" (Comins, 2015). Food insecurity extends from absolute hunger (12%) to other forms of hunger, hidden hunger and over nutrition. May attributes this to a concentrated agricultural sector, which had shrunk from 60,000 commercial farms in 1996 to 40,000 farms in 2007,

[1] FAO estimates that between 2016 and 2018, 26% of South Africa's population was severely food insecure (FAO, 2019).
[2] "Homelands" or "Bantustans" were created by the apartheid government as areas of reserve labour, and to contain black Africans who did not have permission under the apartheid system to live and work in white areas and cities.

with around 500,000 jobs shed. Only 0.6% of those commercial enterprises, 240 farm units, account for 33% of all farm income in South Africa.

May stated that over 60% of the population was urbanised, with just 6% of the population involved in food production. These farmers faced higher input costs as seed prices had increased by 19%, energy by 14% and farm wages by 51% in 2013. Prof. May also mentioned that there had been no reduction in stunting, which is associated with prolonged malnutrition, over the past 20 years, despite investing in child support grants and child health policies (Comins, 2015).

Under the right conditions, advanced technologies can contribute to alleviating food insecurity. Appropriately deployed technologies such as the Internet of Things (IoT), remote sensing technologies and unmanned aerial vehicles (UAVs) allow for increasing amounts of data to be collected on farms. Sensors can collect data about soil and UAVs can collect aerial imagery (African Union High Level Panel on Emerging Technologies and NEPAD, 2018). At the same time, advances in artificial intelligence (AI) systems and techniques such as machine learning (ML) and computer vision systems are enabling the use of this data to identify patterns, make predictions and assist in decision making. ML and computer vision are being used to measure and predict crop yield. Information collected by remote sensing, in combination with ML algorithms and robotics, can be used to observe and respond to variability in crops and crop inputs so as to maximise outputs - a collection of models and techniques referred to as precision agriculture (Tsan et al., 2019).

Digitised agricultural information is increasingly integrated with automation and used to assist decision-making. Digitalisation refers to a different and more advanced phenomenon than digitisation. Although the concepts of digitisation and digitalisation are used interchangeably in much of the literature, it is conceptually useful to distinguish between the two. Digitisation refers to encoding analogue information digitally so that it can be stored, processed, and transmitted by computers (Bloomberg, 2019). Digitalisation refers to a deeper and more transformative process sometimes also captured by the term "*digital transformation*." Gartner defines digitalisation very narrowly within a business frame as "the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business" (Gartner, n.d.). A more encompassing definition is offered by Gray and Rumpe, (2015, p. 1319) who define it as "the integration of multiple technologies into all aspects of daily life that can be digitized." It has also been defined as, "the way in which many domains of social life are restructured around digital communication and media infrastructures" (Bloomberg, 2019).

In addition, another relevant definition to bring to this analysis is the role of public-private interplays (PPIs) as opposed to public-private partnerships (PPPs). The concept of arranging cooperation between private and public actors has grown in heterogeneity and, according to critiques, the 'public-private' moniker is now evolving into a catch-all label for all possible new or known forms of collaboration between public administration and the private sector. Although, there is no consensus on the definitions of PPIs and PPPs, the inability to draw a line of distinction between both concepts has resulted in both being muddled with ambiguities and contention (Williams, Adjin and Tsivor; 2013).

Falch and Henten (2015) describe PPIs as:

> *"[A] government service or private business venture which is operated through a partnership of government and one or more private sector companies; and is a broader concept than PPP as it also includes collaboration schemes without any form of contractual obligation."*

PPIs include a myriad of collaborations between the public and private sectors. PPIs are less binding than PPPs but often broader in their scope and depth. The necessary and sufficient condition for a relationship to be classified as a PPI is for there to be cooperation — as opposed to competition or conflict — between actors from both sectors. The agriculture sector in South Africa requires the collaboration from the private sector to drive the development of the sector so that it can achieve its full potential.

This study will focus on the digitalisation of agriculture and aims to analyse the opportunities and challenges of harnessing the digitalisation of agriculture for the beneficial achievement of the sustainable development. While the digitalisation of agriculture may provide opportunities for achieving sustainable development there needs to be an enabling environment that ensures the beneficial adoption of these technologies within the agriculture sector, without which digitalisation will mirror, or even amplify, existing inequalities.

This study will start with an introduction that will provide an overview of the agriculture sector and then highlight the questions that the project will be answering. **Section two** will provide an overview of the agriculture sector by addressing the issues around labour, land, inequalities, and mechanisation.

Thereafter, **section three** will analyse the general trends of information and communications technology (ICT) in the agriculture sector, which will explore ICT access and usage in rural areas and highlight the use of advanced technologies in the sector. This is followed by **section four**, which will present the areas in which technology is applied in the agriculture sector. Each use case is classified into different areas of digitalisation, specifically for the agricultural sector in South Africa. These areas are around unlocking and optimising the supply chain; automation; data collection; processing of data; aggregation and distribution of information; and unlocking opportunities to finance.

Section five will describe the ICT challenges that the agricultural sector faces, which is mainly around the risks associated to labour, data governance and access to finance. After this analysis, the report will talk about the preconditions required to create an enabling environment for the beneficial use of ICT in the agriculture sector. This is discussed in **section six** and will be addressing the following areas: policy framework; physical infrastructure; ICT infrastructure; skills; finance; and data. And then followed by a set of policy recommendations in **section seven** to discuss the role that government and other public and private stakeholders should be playing to advance the development of the agriculture sector in South Africa.

2. Overview of the agricultural sector in South Africa

In South Africa, the agricultural sector makes up a smaller contribution to GDP in relation to other sectors of the economy. Its percentage share of GDP has declined since 1994, the year of South Africa's first democratic elections, from 3.9% to 2% in 2018 (South Africa's GDP page, 2020). The agriculture, forestry and fishing sectors recorded the highest annual growth at the end of 2018 at 7.9%. The agriculture sector's contribution has waxed and waned in relation to the resources and services sectors (Gillwald et al., 2019).

The Department of Agriculture, Land Reform and Rural Development (DALRRD) is mandated to oversee agricultural activities in South Africa and these include value chains, inputs, production and consumption in the agriculture, forestry and fishery sectors. According to an African Development Bank (AfDB) report, the sector makeup has almost entirely shifted over the last century from mixed subsistence and commercial farming to large scale capital-intensive farming (Gillwald et al., 2019).

This section provides an overview of labour and land inequalities as well as mechanization in the agriculture sector in South Africa. It offers a background to the socio-political issues and economic aspects that have stunted the sector. Issues affecting the sector include employment, climate change, water scarcity, irrigation, lack of title deeds, limited access to finance, especially for small-holder farmers, and infrastructure constraints such as limited road network, storage and warehousing facilities. In addition, proper irrigation is crucial for the agriculture sector, as it stabilizes food production while providing protection against shortages of rainfall that the country is currently faced with (Fanadzo & Ncube, 2018).

2.1. Labour

Even though the agriculture sector has a smaller share of GDP relative to other sectors, it remains pivotal in the provision of employment in the country especially at a rural level. It also counts amongst major sectors that bring foreign currency into the country. Estimates suggest that almost 8.5 million people directly or indirectly rely on the agricultural industry as their primary source of employment and income (Tennant, 2018). In the state's agenda to transform the economy and improve food security, South Africa prioritises land distribution and job creation to achieve its goals as set out in the National Development Plan (NDP). The NDP set a target of creating one million jobs by 2030 and the agriculture sector is seen as a creator of jobs and a driver of inclusive and sustainable growth providing a foundation for nutritious, safe and affordable food. However, there are no clear plans to implement NDP goals. Therefore, the DALRRD focuses on improving food security via job creation in the sector so that its contribution to GDP is improved; at the same time bringing South Africa to the global village in terms of primary animal health care services and enabling trade (Gillwald et al., 2019).

Farm labour is drawn from areas near commercial farms (most in former homelands), as well as from a pool of farm dwellers living on (mainly) white commercial farms and although there is no recent accurate count of farm dwellers, in 2003 it was estimated that three million of the native black population lived on commercial farms. Since then many farm dwellers have been expelled or left unemployed (Andrew, 2016, p. 130). Some farm dwellers are labour tenants tied to the farm through oral or written contracts. They are either paid in kind or by tenancy and below the value of their labour or are afforded access to small pieces of land for subsistence agriculture or given cattle grazing rights (Andrew, 2016, pp. 131–133). Black farm worker families and labour tenants are among the most vulnerable groups in society (Andrew, 2016) and are also subject to seasonal food insecurity and hunger

caused by intra-annual fluctuations in agricultural employment and income that mirror agricultural production cycles (Devereux & Tavener-Smith, 2019).

South Africa is currently grappling with the highest unemployment rate in the world (The Global Economy, 2019), which was 29.1% as of Q4-2019 (Stats SA, 2020). According to a National Treasury study, the agriculture sector creates more unskilled jobs than any other sector for every R1 million ($65,000) of additional output. In 2018, the agricultural economist Thabi Nkosi, found that 90% of those unemployed are considered unskilled and the agriculture sector is the only sector that can employ a large number of unskilled laborers (Nkosi, 2018). She also suggests that despite the sector contributing 12% of export earnings and being one of the major contributors of foreign currency earnings, the sector remains poorly funded in budget allocations. The Quarterly Labour Force Survey (QLFS) collects and reports labour market activities for individuals between ages 15-64 years. According to the QLFS, in 2019 there was a year-on-year drop by 0.2% in those employed in the agriculture sector. Since 1994, employment in the agricultural sector, as a percent of total employment, has halved (from 10.7% to 5.1%). This is in line with Organisation for Economic Co-operation and Development (OECD) trends (8.6% to 4.5%) and this percentage has also halved in China and India between 1994 and 2019 (see Figure 1 below).

Despite agriculture being a relatively smaller contributor to GDP and employment when compared to other African countries, South Africans have expressed interest in returning to the agricultural sector, over the past few years, in light of the land reform debate. The Presidential Jobs Summit of 2018 proposed interventions that earmark agriculture as a key sector for employment creation. These include PPIs to harness job creation by financing the Land Bank,[3] local procurement by value chain in the agri-business and agro-processing sectors and agriculture skills transfer. The Jobs Summit also proposed the allocation of funds based on proposals with criteria and timeframes that promote higher incomes and employment in small-holder agriculture (NEDLAC, 2018). Digitalisation of the agricultural sector should respond to this desire to enable the sector to create more jobs and empower small-holder farmers and black farmers.

In 2010, the Department of Agriculture, Forestry and Fisheries (DAFF)[4] found evidence suggesting that the decline in employment numbers is attributable to the adoption of production technologies and the laws and policies in the regulatory environment (DAFF, ESD, 2010). The Medium-Term Strategic Framework presented in 2017 by DAFF, aimed at reducing rural unemployment from 49% in 2013 to 40% by 2019, by enhancing agricultural productivity (Presidency, 2019). However, in as much as agricultural jobs have increased in the last two quarters of 2019 , there is doubt that the government will be able to create one million jobs by 2030 as highlighted in the NDP.

[3] The Land and Development Bank of South Africa is a government-owned development bank in the Republic of South Africa. The bank is responsible for providing farmers with loans to finance land, equipment, improve assets, and obtain production credit.
[4] DAFF is now part of the Department of Agriculture, Land Reform and Rural Development (DALRRD), which was established in June 2019, by the merger of DAFF and the Department of Rural Development and Land Reform (DRDLR).

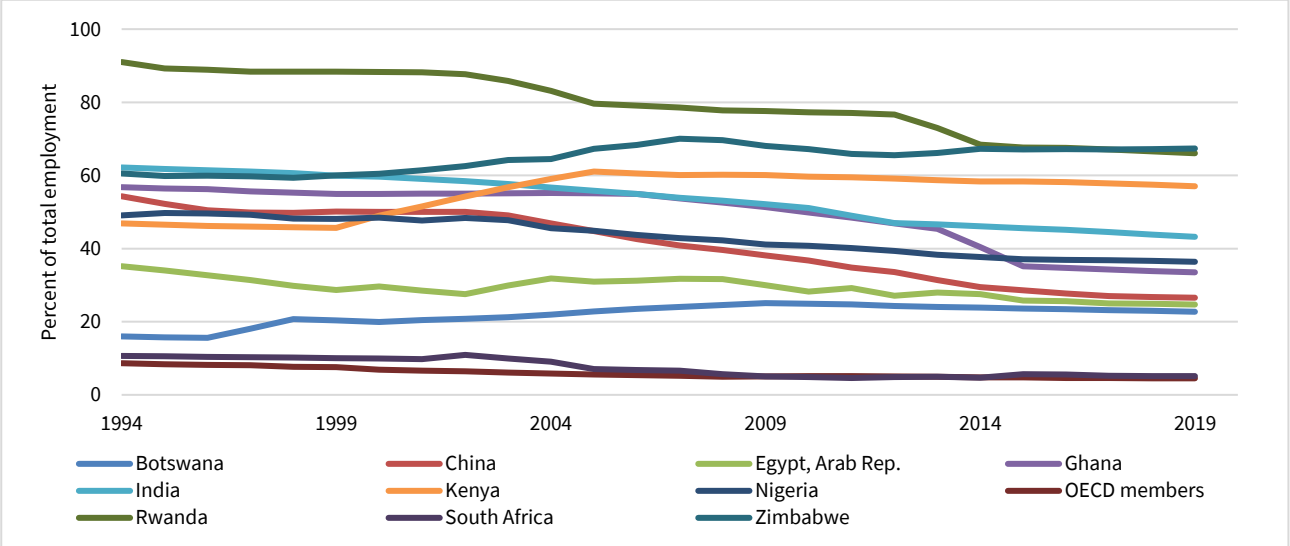

Figure 1: Agricultural employment trends in South Africa vs other countries
Source: World Bank (2019)

2.2. Land

In South Africa, there are around 35,000 registered commercial farms, 40% of which are engaged in field crop farming, with 60% focused on livestock farming (Gillwald et al., 2019). Over 2017/18, agricultural production was estimated at 62.9 million tonnes (a 24% increase from 2016) valued at R281.4 million ($18.3 million), a 4.7% increase. Since 1994, the agricultural sector has shown a growth rate of 7.5% annually (DAFF, 2018). Commercial farmers produce most of the agricultural output in South Africa. The country has a total of close to 70,000 commercial farming units, but only 4% have an annual turnover exceeding R5 million ($326,000) (Naudé, 2018). It is estimated that 75% of all South African farming is conducted by small-holder farmers with small-scale farming being the primary source of food in rural areas. The creation of jobs enshrined in the NDP requires areas under irrigation to be more than doubled, the cultivation of underutilised land in communal areas, the support of commercial agriculture with the highest growth and employment potential and finding creative ways of increasing collaboration between commercial and small-holder farmers (DAFF, 2015).

According to the AfDB, the current political debate surrounding expropriation of land without compensation is creating uncertainty within the agricultural sector, which is delaying investments and strategic business ventures (Gillwald et al., 2019). In addition, the agriculture yield and total production are also directly affected by adverse weather conditions - flooding in some parts of the country and drought in others. The effects of global warming and climate change have without doubt also affected the agricultural output. While this cannot be controlled, it can be avoided by better irrigation planning as well as by the appropriate use of technology (Gillwald et al., 2019).

On the African continent, small-holder agriculture, in particular, is a major contributor to household income in rural areas and is considered to be a much better contributor to household income than the other (limited) rural employment alternatives (Heeks & Hanson, 2020). In South Africa, large-scale commercial farmers are confident in utilising new technologies since they are aware of the benefits of leveraging, for example, drone or satellite imaging to increase productivity. However, these new technologies should not lead to the replacement of farmworkers. Instead they should act as complementary and supporting tools that can provide benefits in terms of both inputs and outputs (Gillwald et al., 2019).

Family farming is considered to be a predominant form of food and agricultural production towards achieving a world free of hunger and poverty by 2030 (FAO and IFAD, 2019). Given the historical racial imbalances that dominate land ownership and agricultural policies in South Africa, there is a need to pay more attention to small-holder farmers who are mostly subsistence farmers. In 2000, Michael Schulze Ehring at Stellenbosch University conducted a study to identify family farming by populating literature on agricultural household theory, as a model of rural economy (Ehring, 2000). The study's general finding was that there is a need to improve efficiency in the allocation of agricultural resources premised on the Land Reform Programme.[5]

2.3. Inequalities in the agricultural sector

Current inequalities in the agricultural sector in South Africa are a product of the apartheid system which segregated people based on the colour of their skin. In 1995, after the end of apartheid, a World Bank report used representative farm-level survey data, for the period 1975 to 1990, from the six major grain-producing areas and one irrigation area to describe the structure and distribution of farm size; to analyse evidence on scale efficiency and the relationship between farm size and efficiency; as well as to describe the effect of apartheid policies on farm size and efficiency in South Africa. The findings of the study were that "farms in the former homelands are not scale-efficient because of historical lack of access to support services and infrastructure, policies that discriminate against farmers in the homelands, and the extremely fragmented and limited land-use rights there" (Van Zyl et al., 1995, p. 39).

In 1995, Van Zyl, Binswanger and Thirtle discussed land's immobility and robustness as a having potential for collateral in the eyes of lending institutions for any farmer who intends to get a loan. However, there is a huge disparity between owners of large pieces of land and small-holder farmers since banks are not willing to provide them with a loan as they are largely subsistence farmers, often with no surpluses to qualify for formal banking. This trend seems to persist in modern-day South Africa, particularly on the basis of the legacy of apartheid land policies. This is perpetuated by the still ongoing debate on land redistribution since the same model of credit and risk diffusion seems to be placed on land as collateral. Since financial resources as well as the integration of ICT technologies such as mobile phone adoption are deficient, there is a need to provide more assistance, including cooperative banking and other savings-mobilisation mechanisms, to rural small-holder farmers. (Van Zyl et al., 1995)

White commercial farming stems from the period after the end of slavery and the rise of settler colonialism when there was an extensive seizure of land that belonged to the native black population that was coerced to provide cheap labour.[6] South Africa's agricultural sector is shaped by the history of apartheid and continues to be characterised by inequality. The agrarian economy is still dominated by large-scale commercial agriculture, which has been monopolised by white farmers (Andrew, 2016). The agricultural sector "continues to function on the whole ensemble of social and racial inequalities on which colonial society was built and the mostly white private land ownership that anchors it" with "many of the oppressive and backward features from the apartheid era still starkly evident" (Andrew, 2016). This is evidenced by the geographical distribution of farming. It is estimated that there are 4

[5] The Land Reform Programme in South Africa is a broader term comprising both land redistribution and land tenure reform. Land reform often takes place within an even broader strategy of agrarian reform: a collection of activities and changes designed to alter the agrarian structure of a country. See: https://www.gov.za/issues/land-reform.

[6] Slavery was fully abolished in 1834 although servitude and indentured labour continued in many forms for some time afterwards.

million small-holder farmers in South Africa are almost entirely black, and farm mainly in former homeland areas which make up 13% of all agricultural land in South Africa. In contrast, there are 35,000 white farmers (mainly large scale farmers) producing approximately 95% of agricultural output on 87% of agricultural land (Pienaar & Traub, 2015).

2.4. Mechanisation

Apartheid policy interventions encouraged the mechanisation of South African farms. Thus, compared to other African and developing world countries, South African farms are highly mechanised. When measuring mechanisation by the average number of agricultural machinery units between 2005 and 2014, South Africa has the third most mechanised agricultural sector in Africa and the most mechanised sector in Sub-Saharan Africa (Kirui & von Braun, 2018). South Africa has twice the average number of agricultural machinery units as the next three sub-Saharan African countries - Tanzania, Nigeria and Zimbabwe combined (Kirui & von Braun, 2018). The acquisition of machinery, tractors and vehicles in the agricultural sector was 63.7% of the total capital expenditure for new assets in 2017 (Lombard, 2019, p. 11). Mechanisation and modernisation can bring with them large repercussions for employment in the agricultural sector, displacing labour in response to factor costs (Simbi & Aliber, 2000). Since agriculture is a labour-intensive sector dominated by a bigger chunk of unskilled labour, the emergence of modern automated ways of undertaking physical tasks could unfortunately lead to job losses.

The dilemmas of mechanisation and labour in the contemporary landscape were addressed recently by a leading agricultural economist in *Stockfarm*:

> *"An industry's level of dependency on manual labour will influence the effect of higher minimum wages. Available mechanisation options for producers will also influence the level of labour substitution in favour of machinery. This puts South African producers in a quandary. It raises the question of whether they should mechanise and employ fewer but more skilled workers who earn higher wages, or whether they should employ more semi-skilled labourers, providing a livelihood to more household dependents. With agriculture earmarked as a sector that can provide more jobs, and given the high unemployment rate in South Africa, government assistance should seriously be considered" (Lombard, 2019, p. 11).*

On the other hand, mechanisation and digitalisation can also create new jobs. The DAFF's Economic Services Directorate, published in 2010, suggests that promoting innovation and entrepreneurship, particularly focusing on the Black Economic Empowerment programme,[7] can lead to an increase in employment opportunities in the agricultural sector (DAFF ESD, 2010). The workers who would have to undergo training through college or technical institution are likely to get some form of permanent employment, which is based on their ability to operate a machine or technologically advanced equipment. Currently, there is potential for the application of AI, big data analytics, blockchain and IoT. Precision agriculture, which will be discussed later, is an example of how these tools can be applied at plant level in providing the inputs they need, such as fertilisers, pesticides and seeds.

[7] The Black Economic Empowerment (BEE) programme is an economic empowerment programme launched by the South African government for the disenfranchised black (African, Coloured, Indian and Chinese) South African citizens to redress the inequalities of Apartheid. See: https://www.nortonrosefulbright.com/en-za/knowledge/publications/fe87cd48/broad-based-black-economic-empowerment--basic-principles.

3. General trends of ICT in agriculture

3.1. ICT access and usage in rural areas

The digitalisation of agriculture in South Africa, as with the digitalisation of other sectors, is predicated on data and device affordability and sufficiently widespread internet access and use. The 2018 After Access survey,[8] conducted by Research ICT Africa (RIA) across 10 African countries, indicated that 53% of South Africans are connected to the internet, which is the highest rate in Sub-Saharan Africa. The survey also found that there is a gap between urban and rural internet users in South Africa. This highlights the level of ICT infrastructure needed for uplifting small-holder farmers who operate primarily in rural areas. While mobile phone ownership is up to 85% in the country, only 47% are smartphones users. This is an important distinction since smartphones have revolutionised the ICT sector and become essential for many agritech solutions in the market.

The 2018 After Access survey undertaken by Research ICT Africa found that the main reason 47% of the South African population is not connected to the internet is due to the high cost of internet-enabled devices and data. Other factors mentioned are limited knowledge of digital skills, illiteracy, and lack of awareness of what the internet is. According to RIA's African Mobile Pricing (RAMP) Index, as of 2020Q1, South Africa ranked amongst the bottom performers in terms of high data prices (33 out of 46 countries), with the lowest price of R100 ($6.51) per 1GB offered by Telkom and Cell C (see Figure 2). In December 2019, this situation prompted the Competition Commission to request that dominant mobile network operators (MNOs), Vodacom and MTN, who offer even higher rates, reduce their prices by 70%. On 1st April 2020, prices have been eventually slashed by MTN and Vodacom to R99 ($6.45) per GB. During the time of writing the, 2020Q2 data collection was in progress to cater for these changes in the RAMP Index at the end of 2020Q2 since data is collected on a quarterly basis. However, in terms of price change relative to other countries, in South Africa data is still expensive.

Quality of service is also a key factor determining the frequency and type of online activities, such as social networking, which 73% of those online claim to use. With South Africa having the highest social media use rate amongst the countries surveyed, South African farmers have the potential to leverage these platforms and applications to reach the end-user market. However, according to After Access data, only 27% of South Africans use the internet to perform work-related activities and even less have an online bank account (17%) or engage in e-commerce (10%). These figures are even smaller in rural areas. Despite the increased levels of connectivity and improvements in infrastructure, there remains a stark digital inequality between those who have the skills and financial resources to use the internet optimally and those who are barely online. As such, until these systemic barriers to meaningful access and use are addressed, many South Africans are likely to be deprived of the direct benefits of digitalisation, particularly in the agricultural sector.

[8] The ICT Access and Use Survey has been conducted triennially for over ten years in 10 core countries, with the survey expanding to 17 countries in 2008. In 2018, the After Access survey was undertaken in 22 countries across the Global South by RIA in Africa, DIRSI in Latin America and LIRNEasia in Asia. See http://www.afteraccess.net and http://www.researchictafrica.net for in-depth African reports, including for South Africa.

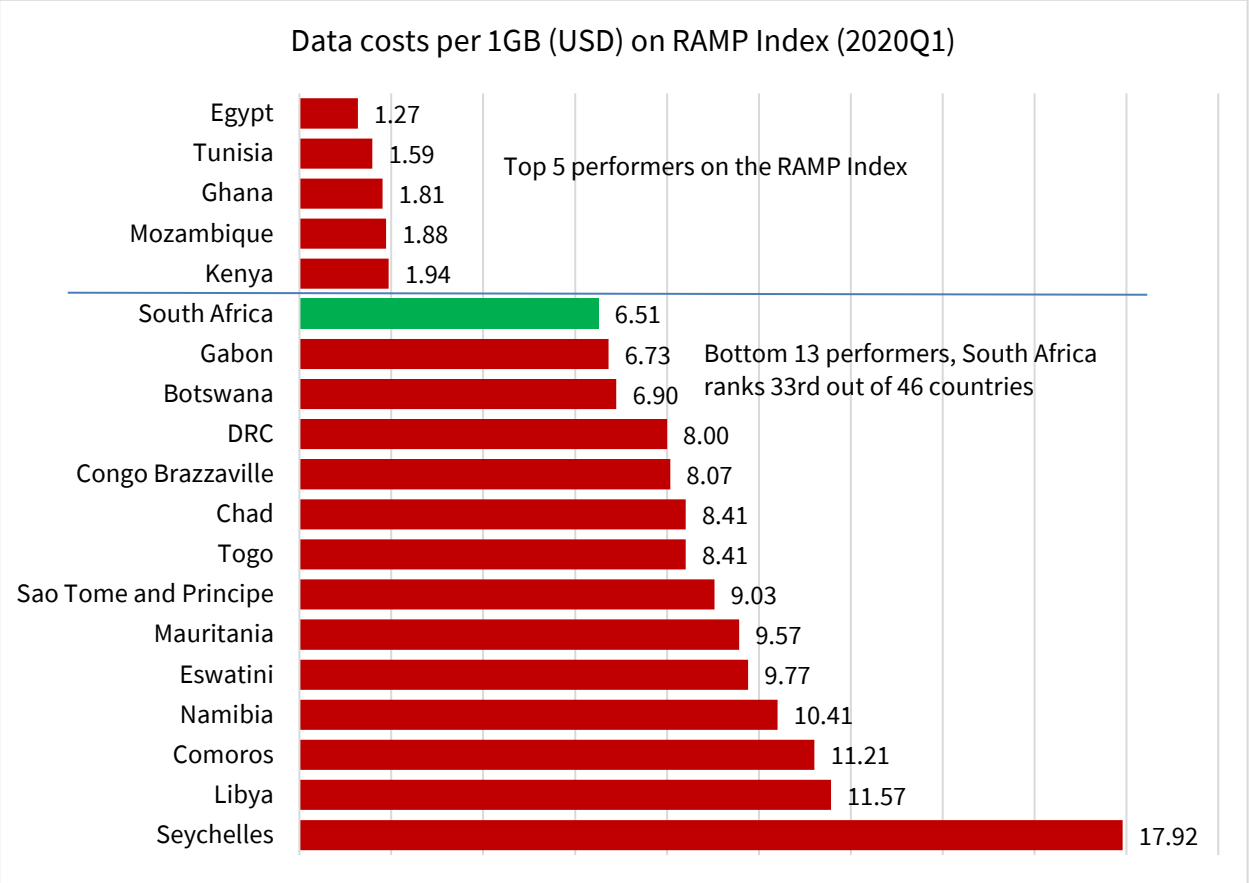

Figure 2: Data costs per 1GB in Africa
Source: Research ICT Africa RAMP Index, Q4-2019

3.2. The use of advanced technologies

Despite the connectivity challenges, mentioned above, the use of advanced technologies and digitalisation have begun to emerge within the South African agricultural sector. Technologies such as wireless communication, data management and analytics tools, remote sensing, robotics, drones, satellite systems and AI, are being integrated to develop services aimed at reducing costs, conserving resources, optimising inputs and maximising outputs.

Many of these digitalising technologies, particularly the on-site technical infrastructures related to data collection and processing, the IoT and AI, can likely only be adopted in large-scale commercial farming operations, primarily because of the cost involved in the technology adoption (Smith, 2018). Benefits to small-scale and rural farmers, when observed, have instead been found to derive from more rudimentary ICT applications like agricultural extension and market information systems accessible through mobile devices (Aker, 2011). This understanding of who does and does not currently benefit from different types of digitalisation in the agricultural sector serves as an underlying basis for the use-case analysis below. There is a generally optimistic understanding that technology can empower small-holder farmers to have a larger footprint in the value chain by addressing key challenges and unlocking untapped opportunities, like making rural farmers visible to providers, customers, distributors or even making them visible to financial service providers. However, as of today, only some of the potential digital applications and services have been successfully deployed in the South African agricultural market, most of which are targeted primarily towards the large-scale, capital-intensive farms that can

afford their services. The next challenge for the agritech industry is to find ways to expand the opportunities unlocked by digitalisation of the sector to emerging and small-holder farmers, who constitute a majority of the South African sector.

There is a need for further evidence on what agritech solutions are better suited to the South African context, as for the African continent more generally. Despite the multiple reports and case studies, evidence remains mixed (Tsan et al., 2019). Moreover, research on this topic should move beyond standard cost-benefit analysis, focused on yield and income metrics, to include other important legal, social, and cultural factors. As such, there is a need for more comprehensive nation-wide analysis to capture the broader effects of the digitalisation of agriculture. This will require governmental collaboration in terms of facilitating data collection endeavours and providing additional financial support for research and would also benefit from more PPIs and research and development within the national private sector.

4. Use cases

With the rapid expansion of the agritech industry, there are multitudes of relevant technologies and use cases emerging across the world, some of which have already taken hold in South Africa. Furthermore, many of these technologies allow for synergies across multiple applications, enabling opportunities for vertical integration. In fact, amongst the companies surveyed, especially those targeting larger producers, it is common to find integrated solutions that incorporate more than one of the services outlined in this section. Based on a review of the different classifications used in the literature, the application areas of digitalisation in the agricultural sector in South Africa have been categorised in this study as follows:

- unlocking and optimising the supply chain;
- automation;
- data collection;
- processing of data;
- aggregation and distribution of information; and
- unlocking opportunities to finance.

4.1. Unlocking and optimising the supply chain

Traditionally, small-holder farmers in rural Africa have been excluded from the global food supply chain. However, recent initiatives have emerged throughout Sub-Saharan Africa to provide these farmers with the services and market access that precluded them from competing with larger producers. These companies combine AI-powered platforms with physical warehouses and logistical infrastructure to enable producers to cut costs and expand their operations through supply chain optimisation.

Digital technologies are also being used for increasing transparency throughout the value chain. This is, at least partially, fuelled by an increasing demand by customers for traceability of food products for both ethical and ecological considerations. However, transparency also carries important benefits for the industry. For instance, some of the largest international retail companies have started to implement blockchain technology to track their agricultural produce sales, providing contracted farmers with access to essential accounting information in return for greater transparency and accountability (Olago, 2019). Furthermore, in South Africa, cloud computing technology is being used to verify regulation compliance from providers along the supply chain.[9]

With the upsurge of e-commerce, several initiatives have emerged to offer more direct market linkages between the farmer and the end-consumer, circumventing traditional intermediaries. Small-holder farmers have limited access to retail markets because of the scale of their production. These e-commerce platforms fill in the gap by connecting customers and small-holder farmers directly, providing the latter with the logistical support to sell and distribute their products and the former with

[9] For example, SGS offers this service under the name of 'Transparency-One'. See: https://www.sgs.co.za/en/agriculture-food/food/digital-solutions-for-food/transparency-one-food-supply-chain.

access to cheaper locally-sourced food.[10] Furthermore, some of these e-market platforms enable farmers to collaborate in the purchase of inputs in bulk and the delivery of larger orders.[11]

4.2. Automation

On agricultural sites themselves, an initial result of digitalisation has been the automation of processes formerly performed by manual labour. Through the cutting of labour costs and increased efficiency of these processes, automation can, in theory, allow agricultural producers to increase the scale and self-sufficiency of operations. A common practical application of this theory is automated irrigation systems, where centralised pump controls can be set on timers or activated remotely. A less common example is the automation of pesticide spraying using UAVs, or drones.

While these solutions sometimes involve complex robotics, the automation of processes does not always involve AI or ML, which are more prevalent in data collection and data processing technologies. Instead, automation in the agriculture sector can be placed in the historical context of previous 20th-century technological developments in industrial manufacturing to increase precision and efficiency while decreasing human intervention. This can often take the form of basic on/off crop spraying devices widely used in South Africa (Spraying Systems Co., n.d.), which have grown in popularity in the wake of extended droughts and water shortages in the country (News24, 2017).

4.3. Data collection

As with every other industry, the future of agriculture is shaped by an increasing datafication of the sector (Taylor & Broeders, 2015). The processing capacity provided by big data analytics and the emergence of innovative data collection methods have given rise to a new form of agriculture commonly referred to as 'precision farming' or 'smart farming'. Precision farming consists of "utilising site-specific data to manage nutrients, pests, water, seeding rates, and other resources in a more efficient manner" (de Carbon, 2016).

A number of innovative collection methods are being used currently in South Africa for crop and livestock monitoring. Crop sensors are being used to measure properties of the soil, such as moisture and compaction. Livestock sensors, which measure vital signs and animal activity, can monitor reproduction cycles or detect health problems.[12] In the simplest models, farmers receive notifications about their farm data via SMS. UAVs, such as drones, and geographic information systems (GISs) are also used to collect aerial imagery for mapping and monitoring damage on crops, crop yield or livestock location (Nel, 2016). Generally, this farm-specific data is combined with external data, such as local weather information sourced from nearby weather stations. Access to this data enables farmers to precisely monitor and manage their inputs and production.

However, since most of these technological applications remain inaccessible to small-holder farmers in the country, some initiatives have emerged that enable the use of personal smartphones as a tool for data collection (Schriber, 2020). For instance, AI-powered smartphone applications are offering direct

[10] Some of these initiatives emerged at the community level, such as 'Umthunzi Farming' in Cape Town.
[11] For example, the 'Khula' app allows farmers to crowd-source and deliver bulk orders for supermarkets, restaurant chains and home delivery. (See Table 1).
[12] For example, GeospaceSA's agricultural project, GeoFarm, can alert farmers when a pregnant cow is going into labour. See: https://www.geospace.co.za/geofarmsa.

diagnoses about crop health from pictures uploaded by the farmer.[13] Provided that digital skills are sufficient amongst small-holder farmers, these processes can allow for the broader data processing capabilities elaborated on below.

4.4. Data processing

New and advanced forms of data collection have, in turn, enabled the use of data processing technologies, which aim to use this information to optimise inputs and outputs in various ways. Often offered in conjunction, several businesses in South Africa have started to provide crop yield predictions and optimised farming inputs, like pesticide and fertiliser use, based on their data collection technologies. Aerial photography, either through GIS satellite systems, drones, or conventional airplanes, is used to monitor the health and quantity of crops. One notable case is that of the Western Cape, where satellite information is being offered free of charge to local farmers.[14] While it is still nascent, the processing of such aerial data through ML and computer vision algorithms has also been advertised under the promise of "making farms more intelligent" (GeoSpaceSA, 2020).

In addition to crop yields, water and livestock data has also been processed in the hopes of data-driven efficiency gains. Based on data collected on the supply and downstream demand for agricultural water use, water administration systems have been set up in several South African locations to calculate the operating procedures of dams and rivers, in order to reduce water losses in the face of limited supply (WAS, 2020). In smaller settings and on farms themselves, irrigation systems have been automated based on, for example, soil moisture data collected through sensors and external weather data (Dennis & Nell, 2002).

4.5. Aggregation and distribution of information

Services that offer data collection and or data processing solutions to small- and large-scale agricultural producers are predicated on the notion that access to site-specific information is key to optimising agricultural outputs. This is an idea at the root of earlier uses of ICTs in agriculture, such as the distribution of agricultural information like weather or best practices through Unstructured Supplementary Service Data (USSD) on mobile phones. A core benefit of these technologies is that they offer some access to vital data for those agricultural producers who cannot afford more advanced data collection and processing technologies.

More modern iterations are free or low-cost, publicly accessible mobile phone applications, which can function as digital agricultural magazines, calculators for feed recipes, or databases for farming advice. Some of these aims to guide real-time decision making by registering the user's location. While two-way communication systems are still limited, some applications also advertise the ability to contact experts or authorities in the case of emergency, directly through the mobile application.

For those that can afford more complicated suites of agricultural technology, some modern information access services come in the form of mobile applications or digital interfaces where automated irrigation pumps can be operated, and crops can be monitored remotely through centralised information management systems. These are sometimes offered as complete services, where automation, data

[13] PANNAR, one of the largest seed producers and suppliers of Africa, developed the app 'Sprout' which includes, among other digital farming tools, the option to upload a picture of infected plants, alongside background information, to obtain a diagnosis. See: http://www.pannar.com/app.

[14] The Western Cape Department of Agriculture (WCDoA) is offering a free website tool called FruitLook to fruit and grape farmers in the Western Cape. FruitLook enables farmers to monitor their water use using spatial data derived from remote sensing. (See Table 1).

collection, processing and integrated information access and management fall under the same product name and brand. The issues regarding the data collection are addressed in the challenges section and the examples are given in the use cases below.

Table 1: Use cases for digitalisation of agriculture in South Africa

Category	Description	Potential benefits	Challenges	Examples of Companies
Unlocking and optimising the supply chain	Solutions geared towards market access and improved logistics, often through coordinating apps	▪ Improve market access ▪ Cut intermediaries ▪ Improve transparency ▪ Access to cheaper inputs ▪ Externalisation of logistics and distribution	▪ Loss of agriculture-related jobs in rural areas due to externalisation ▪ Harm local providers and intermediaries	SGS Transparency-One, Khula
Automation	Solutions that simplify or replace manual labour processes	▪ Increase speed and efficiency ▪ Optimisation of resources ▪ Reduction of labour costs ▪ Opportunities for up-scaling	▪ Reduction of unskilled labour opportunities for vulnerable rural populations ▪ Favours large-scale farmers ▪ High-cost barrier	GeofarmSA, PANNAR Sprout, Water Administration Systems, Lindsay Africa's FieldNET, Yellow Beast, Spraying Systems Co.
Data Collection	Solutions that gather site-specific agricultural data using different sensor technologies	▪ Highly specific/localised actionable information ▪ Increased accuracy and efficiency	▪ High-cost barrier; private databases as opposed to public knowledge (data silo) ▪ Complex legislation and limited funding for entrepreneurs	Agrisol, Rocket Farm, Aerobotics, Technoserve, GeofarmSA, AeroVision, Agri-Sense, DRONESIX, FarmPin, Terracam
Processing of data	Solutions that operationalise and process data into actionable advice or predictions	▪ Data-driven optimisation ▪ Opportunities for vertical integration through ML/AI	▪ Reduction of unskilled labour ▪ Favours large-scale farmers ▪ High-cost barrier ▪ Limited consultation with farmers in design processes	Crop Systems, Water Administration Systems, Rocket Farm, FruitLook
Aggregation and distribution of information	Solutions that help distribute general data and best practices often through mobile phones	▪ Low-cost barrier ▪ Highly scalable	▪ Limited impact/relevance ▪ Supplementary; mostly one-way communication	PANNAR Sprout, Lindsay Africa's FieldNET
Unlocking opportunities for finance	Solutions that leverage digital technologies to provide customised finance and insurance products to farmers	▪ Access to affordable and tailored financial and insurance products ▪ Circumvent barriers of formal finance, such as collaterals ▪ Reduce risks for financial institutions	▪ Privacy risks of data gathering practices ▪ Limited by infrastructure and digital literacy levels, profiling can lead to financial exclusion ▪ Challenges to build trust	Livestock Wealth, FedGroup's Impact Farming, Mobbisurance

4.6. Unlocking opportunities for finance

One of the biggest challenges faced by small-holder farmers in South Africa is the lack of access to funding to start or grow their business. The government has developed several state-owned banks, grants and funding schemes tailored to those excluded from the sector, such as the Land Bank, the Agribusiness Development Agency (ADA), the Isivande Women's Fund or the Land Redistribution for Agricultural Development (LRAD) programme. To counteract the emergence of sector-specific banks and financial institutions, large commercial banks have also developed programmes tailored to emerging farmers.[15] There is also increasing interest from commercial banks to capitalise on the agricultural data captured by private agritech companies.[16] However, a wide gap remains between the formal banking sector and small-holder farmers, which is increasingly being filled by fintech start-ups that leverage digital technologies, such as mobile money, to provide alternative financial solutions to unbanked farmers (Tsan et al., 2019).

One of these alternative systems, called 'crowd farming', enables laypeople to crowdfund farmers by investing in physical assets, such as cows or blueberry bushes.[17] This innovative financial scheme promises benefits for both parties - farmers can receive the necessary working capital to survive the harvesting season while non-experts can invest in secure, tangible assets from their smartphone. Other technologies are also being leveraged to offer insurance products tailored to the needs of emerging farmers. Satellite technology, for instance, enables insurance companies to monitor crops and weather conditions and calculate pay-outs accordingly, preventing information asymmetries and reducing risk (Jackson, 2018).

4.7. Other potential use-cases

Beyond the examples of digitalisation within South Africa's agricultural sector presented above, other notable use cases in other parts of Africa may represent possible future solutions across these categories. One particularly illustrative source of inspiration is the Kenyan agritech sector, the success of which is primarily associated with the role of MNOs in facilitating the uptake of financial and agricultural services (Kirui et al., 2012). For instance, smartphones are currently leveraged in Kenya to determine credit scores and monitor farmers' behaviour in return for access to logistical and financial services.[18] Another successful example on the logistics side, is Hello Tractor in Nigeria and TROTRO Tractor in Ghana, both ride-hailing apps for tractors that connects tractor owners to the nearby farmers. In Ghana, there is also an on-demand shipping logistics service, Truckr, that is a service offered by AgroCenta where small-holder farmers can book a truck or a tricycle to get their products delivered to market.

While many use cases and digital technologies have yet to take hold in South Africa, especially for small-holder farmers, aspirational rhetoric about the potential of such innovations is apparent in government documents, consultancy reports and academia (Western Cape Department of Agriculture and the University of Stellenbosch, 2018). For instance, there is mention of how digitised databases of

[15] Nedbank, one of South Africa's largest commercial banks, has recently partnered with the local drone company Aerobotics in order to gather farm data from large commercial clients and develop new agriculture finance products.
[16] Grobank and Capital Harvest are two prominent private agriculture-focused financial institutions.
[17] Livestock Wealth and FedGroup's Impact Farming claim to offer this service in South Africa from only R576 and R300 ($38 and $20), respectively (BusinessTech, 2019).
[18] An illustrative example of this is iProcure, a supply chain optimisation firm which partnered in 2018 with Safaricom to provide small-holder farmers with access to input suppliers, financial support, stock management services and last-mile distribution. See: https://iprocu.re.

agricultural knowledge could be combined with AI to build semantic products such as query machines to enable more effective agricultural knowledge dissemination (Jahanshiri & Walker, 2015). Blockchain technology is also not currently deployed in the South African context, despite its potential to improve traceability and transparency in regards to land ownership and supply chains (Ge et al., 2017). Overall, it is essential to observe the need for further research and experimentation regarding the feasibility and success of both current and potential uses of agritech solutions reviewed in this section in the South African context.

Table 2: South African agritech start-ups

Agritech Companies in South Africa	
Aerobotics	**Aerobotics:** Aerobotics combines aerial imagery obtained from satellites and drones with ML algorithms to provide pest and disease detection services to farmers, helping them monitor their crops, get early warning of potential risks, and optimise yields. Aerobotics provides farmers with accurate statistics on the health and size of their crops, enabling them to make data-driven decisions. It now operates in 11 countries, including Australia and the United States.
KHULA!	**Khula:** Khula provides supply chain solutions for emerging farmers by connecting them directly to the formal marketplace. The app functions as a virtual crowdsourcing marketplace, connecting multiple farmers for the delivery of large B2B and B2C orders, or the purchase of inputs in bulk. Additionally, the company provides farmers with real-time inventory, access to a cold chain for deliveries, expert advice, and production forecasts. In 2018, the app was awarded 'App of the Year' by MTN Business and they claim to work with over 2,000 South African farmers.
FIELDNET BY LINDSAY	**Lindsay Africa's FieldNET:** Lindsay Africa, a subsidiary of the American Lindsay Corporation based in South Africa, developed the irrigation product FieldNET. FieldNET is a remote irrigation management solution. Their web portal and mobile application enable farmers to control their irrigation system remotely, track water usage, power usage and other metrics, and communicate with in-site operators. Additionally, the farmer can access weather information and receive real-time alerts via text message or on the mobile app.
fruitlook	**FruitLook:** FruitLook is a free web-based tool created by the Western Cape Department of Agriculture (WCDoA) to help farmers in their water and production management via intelligent satellite data products. Using advanced satellite technology, FruitLook collects crop growth, water use information and plant stress information enabling farmers to precisely monitor their production and mitigate rising input costs and water scarcity. The tool has expanded from serving only certain fruit-producing areas in 2014, to over 250,000 hectares. Feedback from producers indicates that FruitLook is an extremely valuable and popular tool, saving the majority of farmers at least 10% of irrigation water per hectare (Kuschke & Cassim, 2020).
PANNAR	**PANNAR Sprout** PANNAR, one of the largest field crop seed producers and suppliers in Africa, has developed a free mobile app to provide technical support to farmers. The app, launched in 2015, contains multiple tools, including a replant calculator, an estimated yield calculator and a hybrid comparison tool. In addition to a crop disease guide, its latest enhancement to date is 'Plant Dr'. This feature enables farmers to submit a picture of their plants for analysis and alerts farmers of potential threats in their area.
AGRISOL A SUSTAINABLE FUTURE	**Agrisol:** Operating since 2010, Agrisol has developed an advanced GIS that collects grid samples, physical soil data, satellite images and weather statistics. This information is then processed to deliver independent timely site-specific recommendations to the farmers. The data gets aggregated into a single user-friendly platform, which farmers can easily access from their laptop or mobile phone and use it to inform their decisions. Furthermore, given the user consent, this data can be shared with relevant external providers to connect the farmer to related products and services, such as agricultural resources or financial and insurance products. In contrast to other digital solutions developed directly by input providers, Agrisol claims to be fully independent in its recommendations since it does not sell products directly to the farmer.
LIVE STOCK WEALTH PRIDE FARMING WEALTH	**Livestock Wealth:** In 2015, Livestock Wealth introduced an innovative crowdfunding alternative to traditional agricultural investment under the name of 'crowd farming'. Crowd farming enables small investors to buy physical farm assets (such as a cow, an ox, or a macadamia tree) from the farmer. The farmer can use the cash from the transaction to sustain its activity, looking after the sold assets, until harvest. The produce is then marketed by Livestock Wealth to ensure higher earnings, which the farmer can use to buy back the asset by paying the returns to the investor. The innovative aspect of this method, which is being replicated by other companies, is that it enables farmers to use their physical assets as collateral, which is not generally accepted by conventional financial institutions. Additionally, the relatively low price of the investment products offered, and the simple platform interface, makes investing in agriculture more accessible to the non-expert public.

5. Challenges of ICT in the agricultural sector

Much of the narrative around the potential of more advanced forms of agricultural digitalisation would benefit from locating these technological developments in the context of South Africa's extreme digital inequality, in order to ensure that these are not further exacerbated. Additional safeguards need to be put in place to align the commercial imperatives of the sector with fundamental rights and ethical practices and to address some of the preconditions at the national level, particularly in relation to human development, that would enable a more equitable deployment and a more informed use thereof.

Unless specific efforts to ensure digital inclusion and tackle the country's particular developmental challenges are put in place, it is likely that the benefits offered by advanced technologies in the agricultural sector, such as AI and ML, will only be accessible to those with the physical and financial resources to deploy them.

5.1. Risks to the labour market

New agricultural technologies, just like mobile phones and the internet, have the potential to stimulate the economy and create new jobs, but the automation and efficiencies associated with them could also reduce employment opportunities for vulnerable rural populations with limited options. The above surveying of South African use cases suggests that services focused on the digitalisation of agriculture are aimed, in part, at cutting labour costs and that any direct jobs created are likely to be high-skilled. The technological development of the agricultural sector is, however, constrained by a lack of qualified professionals and technicians, as agricultural colleges are struggling to deliver technically skilled people required for farm management and to increase students' exposure to modern farming practices and practical fieldwork (Reinhardt, 2018).

By reducing labour opportunities for poor and rural communities, the economic growth of the agricultural sector risks harming local economies. Large-scale commercial farmers make considerable income from high-efficiency agricultural sites that are linked to distant markets through international supply chains. As they provide less local employment and the products, profits and consumption expenditures often bypass local markets, the local informal economy may not share any residual benefits (Du Toit, 2016). While general ICT technologies, such as mobile phones, have been known to improve households' access to a wide range of markets and sources of market information, thus strengthening rural resilience, their benefit for communities are far more limited (Heeks & Hanson, 2020). These findings suggest that discussions of the positive impacts of agricultural digitalisation and ICT cannot focus only on agricultural outputs, market access and efficiency gains while ignoring broader long-term indicators like the overall welfare of communities (Duncombe, 2016). As such, a major challenge to agricultural digitalisation will be mitigating the risks to the labour market through, for example, controlled deployment and the re-skilling and retraining of labourers (Naudé, 2018b).

5.2. Data governance

There is much debate around how personal data is collected, stored and used, especially in industries that handle large quantities of data, which is increasingly the case of the agricultural sector. Through the generation, collection and control of large quantities of farmers' data, agritech companies have gained significant leverage over the sector (Ryan, 2019).

Precision agriculture tools, such as drones, satellite imaging and sensors, collect large amounts of data, which could include sensitive information, such as information about farming practices. This data may also contain personally identifiable information (PII) on individual farmers or farm labourers (names, address, property or housing location), as well as information on crop types and yields, which could give an indication of a farmer's income or the value of their farm. Without the appropriate regulation, farmers could be vulnerable to the exploitation or misuse of their data (Ferris, 2017). For instance, providers of insurance and financial products could use this information to limit or exclude farmers from access to financial services (Gitonga, 2019). Additionally, farmers, and particularly small-holder farmers, can be subject to great risk when delegating important decisions on AI solutions that can be vulnerable to algorithmic bias or inaccurate data (Zhang et al., 2015).

Furthermore, there are questions about who owns the data collected from farmers and who is entitled to beneficiate from it. There are large amounts of information collected and supplied by farmers being leveraged to develop innovative commercial applications and services. However, it is essential that the companies involved in the development and sale of these products, compensate the data originators and gatherers accordingly, and ensure that the data collected, instead of being siloed, is also made available to national public and research bodies for socially beneficial non-commercial purposes (Rotz et al., 2019).

Given these challenges, the state has a critical role in ensuring that comprehensive regulation is put in place so that the process of digitalisation responds to the needs of all farmers, minimising potential negative implications, particularly for the most vulnerable stakeholders. South Africa and the rest of the continent needs more robust policy and governance frameworks to ensure that agritech solutions are beneficial and rights-respecting. This would involve a mixture of existing and new regulation, as well as a set of sector-specific policies. For example, privacy and data protection legislation, while not explicitly dealing with the agritech sector, is fundamental to ensuring that the rights to privacy and other related rights, are protected from harmful practices. While South Africa does have a data protection framework in the form of the Protection of Personal Information (POPI) Act of 2013, large parts of it are still not operational, which has thus far resulted in insufficient clarity and enforced compliance in, for example, the transparency of data-sharing. Additional data governance regulation will likely be required for the management of big data and AI-powered algorithms. Open data models and frameworks should also be considered to promote the exchange of data and innovation across the industry.

5.3. Access to finance

As previously mentioned, one of the main barriers for small-holder farmers to access more complex, and hence more effective, technology is affordability. Lack of access to credit is considered a key driver behind the poor performance of small-holder farmers compared to large commercial farmers in South Africa (Chisasa & Makina, 2012). If the issue of unequal access to finance is not addressed, the digitalisation of the sector will inevitably further broaden this performance gap. While there is an increasing number of initiatives aimed at providing financial assistance for the uptake of digital solutions, at times even offered by agritech companies themselves, a coordinated effort by the government, the formal financial sector and the emerging fintech sector is required to promote customised and safe financial instruments that ensure equitable access to agritech innovation.

However, there are some potential risks with the expansion of fintech companies that promise to 'bank the unbanked' arising from the lack of regulation of this emerging sector. For instance, Kenya, one of

the early adopters of digital finance solutions, has witnessed an upsurge in defaults for digital loans, leaving millions of Kenyans indebted and blacklisted (Gitonga, 2019). This resonates with the microloan crisis of post-apartheid South Africa, whose effects are still felt by those affected (Bateman, 2014). While the surge of fintech solutions in Africa has been met by an ample public demand, the Kenyan experience suggests the importance of implementing a robust regulatory and legal framework to protect small-holder farmers from risking their savings and potentially jeopardising their creditworthiness, further restricting their access to finance in the future. One of the mechanisms of the sector that should be regulated is the monitoring and data gathering practices that might enable fintech companies to exert excessive control over the farmer's behaviour and to screen out those deemed as 'risky' or 'unprofitable' based on private algorithmic models. While the POPI Act is not fully operational, it will require firms to have data protection officers and data protection policies. These policies should ensure consent from farmers regarding the conditions of their loans, including information about the types of data gathered and its intended use.

6. Creating an enabling environment for the beneficial use of ICT in the agricultural sector

The sections above have illustrated a diverse and evolving ecosystem of technological solutions that, while innovative and potentially beneficial to the overall growth of the agricultural sector and a number of stakeholders, nevertheless faces a number of challenges. Facing these challenges will likely mean creating the right conditions for responsible agricultural and ICT development while mitigating potential risks. In order for growth through digitalisation to be sustainable and its potential benefits extended across the sector to include small-holder farmers, both new and pre-existing inequalities will need to be addressed, in part through sound and inclusive policy. In other words, the transformation of South African agriculture will require the right enabling environment. The preconditions for the beneficial digitalisation of agriculture involve:

- a policy framework;
- physical and ICT infrastructure;
- skills;
- finance; and
- data.

6.1. Policy framework

The current policy framework needs to be further updated to meet the rapid developments in the agritech sector. Agricultural policy in South Africa has mostly overlooked the digitalisation of the sector, failing to provide the appropriate incentives and safeguards for its development, which in turn has been primarily driven by the private sector. The ICT Research, Development, and Innovation (RDI) Roadmap (2014) considered the role of ICT in the agricultural sector in improving agricultural production and supporting emerging farmers. The 2017 National e-Strategy outlines a nine-point sectoral intervention plan, which includes the revitalisation of the agricultural sector through the deployment of 'smart farming' initiatives throughout the agriculture value chain, with an emphasis on emerging and small-holder farmers. However, the intentions outlined in these policy papers have not materialised into an actionable national strategy to support the digitalisation of the sector. Despite this delay, agriculture has been cited by President Cyril Ramaphosa (2020) as an important aspect of the government's vision for the 4th Industrial Revolution (4IR), to be addressed by the industry leaders, public officials, and other stakeholders that make up the President's recently appointed 4IR Commission.[19]

On the regional level, the Western Cape's Department of Agriculture (WCDoA) and the Eastern Cape Socio Economic Consultative Council (ECSECC) have each released reports on the digitalisation of the agricultural sector, assessing their local strengths and challenges in harnessing the latest technological innovations.

Lack of transparency and clarity around the regulation governing the collection, processing and management of data has been identified as a contributing factor to farmers' reluctance to engage in the sharing of their farm data, as required to benefit from smart farming initiatives (Wiseman et al., 2019). Robust data protection regulation, instead of mandatory enforcement, would promote trust

[19] A list of members and terms of reference are available via the Government Gazette (2019). See also, Gillwald et al. (2019).

amongst farmers that their rights will be protected when engaging in commercial data-sharing practices and agreements.

South Africa has considerably strong data protection legislation, as compared to its African counterparts. The constitution recognises the right to privacy, and the POPI Act promotes the protection of personal information processed by public and private bodies. The POPI Act shares some similarities to the European Union's (EU) 2016 General Data Protection Regulation (GDPR), although the latter is more comprehensive, for instance, by introducing fines for noncompliance. While enacted in 2013, the POPI is not fully operational, and only a fraction of the POPI Act's provisions have come into effect, amongst which was the appointment of the Information Regulator. Although some companies in the sector have already started working towards ensuring compliance, until the POPI Act is fully in force, there is a lack of clarity about how this regulation will affect the agricultural sector specifically.

Furthermore, there are no examples of sector-specific standards or codes of conduct attending to the particularities of agricultural data such as the ones found in the EU, New Zealand, or the United States. The EU Code of Conduct on Agricultural Data Sharing by Contractual Agreement, for instance, outlines best practices regarding data-sharing contractual relations to ensure that the data originator (the farmer or collector) has a leading role in controlling not only who can access the data, but also how it is accessed and used. South Africa should consider developing national guidelines in this vein, even if non-binding, that expand beyond the POPI Act's mandates and ensure transparency and fairness in data-sharing practices of both personal and non-personal agricultural data. Such guidelines should also address cross-cutting concerns regarding intellectual property rights and cybersecurity risks.

While examples of AI in the South African agricultural sector remain scarce, there are many emerging potential use cases across all the application areas outlined above. Hence, there is an increasing need for AI-specific regulation. Beyond providing financial support for academic institutions and research centres, the South African government has had limited engagement in the promotion of AI policy (Brandusesc et al., 2017). In April 2019, the President appointed the members of the Presidential Commission on the Fourth Industrial Revolution, with the mandate to assist the government in taking advantage of the opportunities presented by new technologies, such as AI. On this front, South Africa has joined other African countries, such as Kenya and Tunisia, who have also recently created special taskforces to tackle the potential of AI.[20] There have also been talks about the creation of a National Artificial Intelligence Institute (Marwala, 2020). Nevertheless, South Africa has not yet formalised any policy documents or bills regarding the regulation of AI. A proactive policy approach in collaboration with all stakeholders would likely incentivise a more democratised adoption of these technologies across the agricultural sector. This could be achieved through the introduction of industry-specific ethical guidelines in alignment with international standards and rules (Access Partnership & University of Pretoria, 2018).

Finally, the government should actively collaborate with industry leaders to ensure that the regulations and policies put in place do not deter innovation and entrepreneurship in the sector. A recent GreenCape report, for instance, identified the complex and onerous legislation governing the licensing and regulation of drones in South Africa as a primary barrier for the sector (Kuschke & Cassim, 2019). This is even more relevant if considering that some of the most successful South African agritech

[20] Kenya announced its expert-led 'Distributed Ledgers Technology [Blockchain] and Artificial Intelligence Taskforce' in 2018 (Kenyan Wallstreet, 2018), while in Tunisia a taskforce was reportedly convened for the creation of a national AI policy in conjunction with a partnership event between the UNESCO Chair on Science, Technology and Innovation Policy, and Tunisia's National Agency for Scientific Research Promotion (ANPR, 2018).

companies specialise in drone technology. Policymakers need to strike a balance between creating policies to ensure the rights of farmers and easing restrictions, fees and regulatory hurdles to support entrepreneurs and emerging businesses in the agritech sector - two objectives that are not mutually exclusive.

6.2. Physical and ICT infrastructure

A conducive infrastructural landscape is essential to fostering ICT usage in the agricultural sector in South Africa. This includes but is not limited to electricity, water, transport, and ICT infrastructures. One of the particularly pressing issues in South Africa is power outages and rolling blackouts. Stable electricity supply is fundamental for the use of any ICTs, from mobile phones and the internet, to more complex technologies in the broader ICT sector, such as AI, IoT, or robotics.

The utilisation of both simple and more complex ICTs, like AI and mobile phone usage for instance, will in all likelihood increase in the agriculture sector if there is a constant and reliable supply of electricity in South Africa. Innovation and real-time adoption of agricultural advancements that take place at a global scale are encouraged if users have the infrastructure that allows it. Furthermore, most small-holder farmers are likely to obtain information regarding agriculture developments from national radio or television broadcast. This is because South Africa has a good television penetration rate in both urban (85%) and rural areas (70%) and access to radio at 71% and 61%, respectively (Gillwald et al., 2018). However, opportunities to disseminate useful information through agricultural programming are currently at-risk of being impeded by load shedding and unreliable electricity supply. Moreover, small-holder farmers are likely to have difficulty following or discovering agricultural information and technological developments through online platforms. Since 60% of South Africans living in rural areas – 31% of the total population – have no access to electricity (Jamal, 2015), there is a need to move faster in improving both access to electricity as well as its reliability.

At the same time, it is important to improve the energy efficiency of critical ICT infrastructure such as data centres to allow for the increased use of ICT devices, software usage as an agriculture service, mobile applications in farming, digital media streaming and the expected growth of IoT. Energy consumption is currently growing in data centres and appropriate technical action needs to be taken even if it means the use of imported equipment, that should be regulated in terms of their energy consumption. Similarly, infrastructure for the collection and distribution of water will need to find a balance between ensuring access while increasing efficiency in the face of frequent droughts and limited supply.

Agricultural development is also dependant on a well-maintained transport infrastructure. Road and rail are the main means of freight transportation in South Africa with a few movements of agricultural products facilitated by air and shipping. While South Africa's road infrastructure is comparatively extensive for the region, transportation from the farm gate to the consumer can be a complex process for small-holder farmers in rural areas who have surplus to sell. There is diversity of value chains in terms of size, location, distance, and roads that may be inhibited by poorly maintained thoroughfares, an inefficient supply chain, or high fuel prices. A well-functioning transport infrastructure complemented by effective communication systems between different actors in the value chain could increase the efficiency and involvement of small-holder producers and make digitalisation more inclusive and thus effective.

Furthermore, digitalisation of agriculture requires high bandwidth, low latency, and reliable connections. In addition to a stable supply of electricity, this will also require robust ICT infrastructure.

In order to maintain global competitiveness and provide high-speed and quality service on which next-generation agricultural technologies will depend, South Africa needs to encourage the creation of an environment for investing in constantly evolving technologies. Investments in infrastructure will need to be geared towards enabling growth and innovation while ensuring that development is inclusive, which means incentivising investment in under-serviced areas and creating strategies for access that can complement cell towers like free public Wi-Fi, small cell networks or the extension of spectrum. While South Africa has an impressive 90% 3G coverage in rural areas, access to ICT infrastructure and its widespread use is also considerably inhibited by high data prices. An effective enabling environment would necessitate a well-regulated and competitive market in which consistent access to ICT infrastructure is far more affordable, and in which the data-intensive technologies likely to emerge in the agricultural sector can thrive.

6.3. Skills

According RIA's After Access Survey, South Africa's poor educational attainment levels are among the reasons why close to half of the South African population is not connected. Recent statistics from the OECD (2019) for example cite that only 7% of South African adults have gone through tertiary education, while UNESCO (2017) saw a 6% decrease in literacy rates between 2010 and 2017, from 93% to 87% among South Africans above the age of 15. The After Access survey suggests that in South Africa, there is an increase in the digital divide "not only between those with access to the internet but also between those who are connected and have the means and skills to utilise the internet optimally and those who are not" (Gillwald et al., 2018). This stems from an inability to use internet-enabled smartphones and the language used in internet content. E-literacy should be improved by enabling access to internet content in local languages, which would then connect much of the small-holder farming population, which is likely rural-based. Such digital literacy should be geared towards creating not only consumers of digital content but also producers in order to foster an inclusive and more self-sufficient digital ecosystem.

In the face of a changing agricultural landscape, digital skills will be essential both for innovation to occur and for growth to be inclusive. While digital literacy programs will help rural and small-scale agricultural workers take advantage of low-cost technological solutions and get access to information, universities and governments can coordinate programs for high-skilled jobs that will continue to emerge through the development of technologies like IoT and AI.

6.4. Finance

As previously identified, access to finance is a major deterrent for both the adoption and development of agritech solutions in South Africa. Both the formal banking sector and the emerging fintech sector, fuelled by the potential of mobile money, are going to play an essential role in ensuring a rapid and all-embracing digitalisation of the sector.

The Land Bank has key strategy pillars such as agricultural sector growth, supply chain development, agricultural innovation, as well as production expansion and intensification. The bank is responsible for providing farmers with loans to finance land, equipment, improve assets and obtain production credit (Land Bank, 2018). Currently, the bank does not receive direct funding from the government. However, the government should consider taking steps to provide funding to the bank so that it can rely less on commercial markets to raise funding. This will likely lead to more favourable interests, making loans more affordable to farmers.

The 2020 budget has allocated R495.1 million ($32 million) towards the Department of Agriculture, Land Reform and Rural Development, with the objective to improve agricultural sector exports. The Agricultural Development Agency (AGDA), a recently launched private sector initiative, has committed to injecting investments worth R25 billion ($1.6 billion) into South Africa's agriculture, which could significantly push advancements in the sector. Recently, an additional bank, Grobank has joined the South African banking sector with the aim to provide financial resources to emerging farmers and small, medium, and micro enterprises (SMMEs) who were not able to obtain funding for their projects elsewhere (Nkosi & Sihlobo, 2019). Responding to the uprise of the agritech sector, Grobank has announced the introduction of customised products tailored to fund the uptake of digital and technological solutions (Rooy, 2020).

The Kenyan experience has shown how mobile money can also play a fundamental role in improving financial inclusion and technology uptake. With only 8% of South Africans using mobile money, compared to 83% in Kenya, more needs to be done by policymakers to support and promote the use of these services (Gillwald et al., 2018). Fintech's ability to reduce information asymmetries and transactional costs makes it a valuable tool in the democratisation of access to finance and agritech applications. However, the potential to monitor the farmer's behavioural patterns or monetise on their digital footprints must be adequately regulated to establish trustworthiness. Other than mobile money services, the use of crowdfunding platforms, while still very low in Africa, was identified as another emerging source of funding for small-scale farmers.

The local agritech sector also needs to be supported with more finance and funding opportunities if South Africa wants to compete on a global scale. Limited access to seed funding has been identified as a critical barrier for the local start-up ecosystem (Kuschke & Cassim, 2019). A considerable amount of the start-ups identified during the mapping exercise were financially constrained or even forced out of business (Jackson, 2020). Funding opportunities can come from either government schemes or local investors, such as venture capital firms. However, currently, many local agritech companies must look for funding abroad. Partnerships between the industry and commercial banks, such as the one between Nedbank and Aerobotics, are a very promising avenue. Ultimately, strengthening the local agritech industry will ensure that the profits and data generated by the sector stay in the country.

6.5. Data

Data is at the centre of the digitalisation of agriculture. This includes data collected from crops (through manual measurements or remote sensing); aerial photography (from planes or UAVs), GIS and mapping data; meteorological data (such as temperature, rainfall, wind, and humidity), data about farm machinery, and data about agricultural inputs (such as pesticides and fertilisers). Farming data can be collected on-site, bought from companies, or provided as a public good by government agencies, international organisations, non-governmental organisations, and open data repositories. Open or public data available to South African farmers includes statistical data from the FAO Corporate Statistical Database, FAOSTAT.

FAO recommends conducting agricultural censuses every 10 years (Nkosi & Sihlobo, 2019). Statistics South Africa (Stats SA) is in charge of conducting a national Census of Commercial Agriculture (CoCA) every five years. The CoCA collects information about farm size, farm use, farm loss, crop production, livestock numbers, machinery usage, employment, as well as financial information. However, the 2012 census did not take place due to lack of funding. Furthermore, the data collection for the 2017 census was only completed in November 2019 and is yet to be released. Stats SA also runs biennial agricultural

surveys. Stats SA is currently facing a funding crisis with its advisory council considering it to be at a 'tipping point', and threatening to resign if the agency does not receive funding and fill 'frozen posts' (Cronje, 2020). Structural weaknesses in the national statistical systems throughout sub-Saharan Africa has been identified as a critical impediment for the continent to start reaping the benefits of the 'data revolution' (Center for Global Development, 2014). Hence it is vital to improve the funding and capabilities of Stats SA to ensure the production of timely, accurate and unbiased data on the agricultural sector.

Benefiting from the digitalisation of agriculture will also require supporting data infrastructures. South Africa's spatial data infrastructures are governed by the Spatial Data Infrastructures Act (2003), which is in force but not fully implemented. This Act established the South African Spatial Data Infrastructure (SASDI) framework as developed by the Committee for Spatial Information (CSI), which makes policies and technical standards on the use of geographical and mapping data. Amongst the objectives of SASDI is to create an enabling environment that promotes cooperation and coordination in the use and sharing of geographical information. Given the relevance of GIS data to the agritech sector, it is essential that SASDI keeps up with the requirements of the sector and promotes innovation and collaboration in the field.

6.5.1. Open Data

While South Africa fairs better than most of its African counterparts in the World Wide Web Foundation's Open Data Barometer, it still lags behind in comparison to other countries of similar income levels (Schalkwy, 2017). Access to public data, such as land records, which is currently very limited in South Africa, is essential to develop locally relevant products and services (Brandusesc et al., 2017). Furthermore, open data regulation and data sharing incentives need to be put in place to avoid data silos in the corporate realm (Rotz et al., 2019). The democratisation of data control is essential to ensure the right of all stakeholders to participate in its economic and social benefits. This would require the development of strong partnerships across the private sector, public bodies, and research institutions, including universities, to increase the quantity, quality, and interoperability of agricultural data available. In the move towards making data open by default, it is crucial to develop clear data ownership and governance regulations. Furthermore, beyond access, it is also important to engage in capacity building activities regarding the management of open data to empower farmers and local communities.

South Africa needs to engage with the numerous initiatives emerging around the world regarding open agricultural data. The Global Open Data for Agriculture and Nutrition (GODAN) initiative for instance, is a global movement established in 2014 that promotes the 'proactive sharing of open data to make information about agriculture and nutrition available, accessible and usable' (GODAN, 2020). Another notable example is the International Open Data Charter, which has developed an 'Open Up Guide on Agriculture' that provides guidance to policymakers. While the UK and the US have been pioneers in the development of open data policy, some African countries are also taking action on this regard. During the 2017 Ministerial Conference on Global Open Data for Agriculture and Nutrition, held in Kenya and co-hosted by GODAN, agricultural ministers from eight African countries signed the Nairobi Declaration, committing to develop open data policy frameworks in their respective countries. As part of the declaration, they created the African Intergovernmental Network on Open Data for Agriculture and Nutrition. South Africa must start to play a more active role in these international partnerships and collaborative efforts.

7. Policy recommendations

There is a need for policymakers to view the agriculture sector as part of a wider global value chain ecosystem. In order to ensure an inclusive and rapid digitalisation of the sector, there are a series of challenges highlighted in this paper that need to be addressed: increasing small-holder farmers' visibility across the value chain; improving the physical and ICT infrastructure related to the sector; and introducing policy frameworks for open data, data protection and data governance that address the needs of both farmers and local entrepreneurs. Furthermore, the government should promote an inclusive environment for PPIs as well as for large scale commercial farmers to support small-holder farmers. These partnerships across stakeholders can aid in uplifting emerging and small-scale subsistence farmers into successful commercial farmers by harnessing the potential of agritech innovation. Under the right conditions, the digitalisation of the South African agricultural sector creates a unique opportunity to tackle the environmental and socioeconomic challenges of the future as well as to address historical inequalities and deficiencies. A list of detailed policy recommendations to bring about the enabling environment outlined in the previous section are highlighted below. These actionable suggestions have the objective of ensuring all South African farmers can harvest the benefits of digitalisation so that the sector can compete globally by uplifting local innovation as well as protecting small and emerging farmers.

7.1. Update policy frameworks

There is a need **to develop policies that encourage the uptake of appropriate technology within the agriculture sector while also addressing the emerging challenges regarding data protection, data ownership and governance.** As a result of the datafication of the sector, there is a need to develop robust data protection and privacy regulations. This would involve both harnessing the full potential of current legislation, such as the POPI Act while also working to develop forward-looking regulations, such as AI ethical guidelines, to stay up to date with the rapid pace of the agritech industry. Sector-specific guidelines and codes of conduct regarding contractual agreements will also be crucial to promote trust amongst farmers that their rights will be protected when engaging in data-sharing practices. Furthermore, the government needs to increase its commitment to making agricultural data open by default, while also addressing potential ownership rights and security concerns. Ensuring farmers' right to privacy is equally important in the financial and banking sector, especially regarding emerging fintech applications that rely on the use of their data. Finally, any policies and regulations adopted by the government should also take into consideration the requirements of the emerging local agritech industry to ensure that they do not hamper innovation and entrepreneurial efforts in the sector.

7.2. Circumvent the limitations of current physical infrastructure

There is a need **to ensure a more sustainable and inclusive mechanisation of the agricultural sector by encouraging the sharing of equipment (such as tractors) as a way to provide logistical support for small-holder farmers to gain efficient access to the market and the wider value chain.** Small-holder farmers are mostly located in rural areas, with very little access to proper road infrastructure and, sometimes, with no access to a vehicle to transport their surplus. Therefore, based on the examples from Nigeria and Ghana mentioned above (Hello Tractor, TROTRO Tractor, and Truckr), there is a potential for government and policymakers to encourage machinery sharing whereby small-holder farmers can connect to nearby farmers to access their tractors and trucks for delivery, at an affordable

cost. Apart from encouraging responsible farming practices, this could also provide a business opportunity for delivery services and agriculture vehicles owners by offering e-hailing services to small-holder farmers who cannot afford to purchase this equipment.

Furthermore, there is a need **to respond to water and power shortages by promoting innovative and sustainable practices, especially amongst small-holder farmers.** Government and policymakers should amend power and water policies, and improve water and electricity governance systems, as well as increase water capacity for the agriculture sector. However, significant improvements to the physical infrastructure are unlikely to materialise in the short and medium run, while environmental risks, such as droughts, are likely to become worse in the coming years. Hence, there is a lot of potential in harnessing emerging technological solutions that enable precise control of water use, and other inputs, on the farm, such as the Western Cape's free satellite image service, FruitLook. With regards to the power shortages, there is a need to consider alternative sources of energy for the sector, as a measure to make the sector more sustainable. The restrictions and bottlenecks to independent power producers and the self-generation of electricity must be addressed. The government should also promote solar and renewable energy while making rural electrification more resilient and less carbon intensive. Furthermore, the need for innovative alternatives to the national water and power supply must be considered as an opportunity to create new avenues for PPIs and indirect employment.

7.3. Address digital inequalities

Government needs **to work with the private sector to strengthen digital infrastructure to ensure constant and reliable internet connectivity in rural areas while enacting regulation that makes data and smartphone devices more accessible for small-holder farmers and poorer communities.** Apart from power, water, and road infrastructure, improving access to the internet is crucial to enable the digitalisation of the agriculture sector. South Africa is in a position to take advantage of the high 3G coverage in rural areas (90%) to work with the IoT service providers to inform and educate small-scale farmer on the disruptive potential of digital technologies in the sector. While addressing the digital divide and educating farmers is a costly exercise, government needs to raise funds and unlock regulatory bottlenecks to address the current digital divide between urban and rural areas. This could be done, for instance, through the assignment of currently unused spectrum in rural areas to alternative network deployment mechanisms, such as community networks (Gillwald et al., 2018). Another topic that regulators need to address is the high prices of data and smartphones. One way to mitigate the high device costs, in the medium term, is to promote local production of these devices.

7.4. Coordinate efforts to upskill the sector

There is a need **to reduce the agricultural skills gap in secondary school and university by creating educational programmes that address the changing nature of the agriculture sector, while at the same time supporting the entrepreneurship opportunities that are emerging along the value chain.** The digitalisation of the agricultural sector presents opportunities to reduce unemployment and poverty in rural communities, as well as contributing towards economic growth with the creation of high-skill jobs. Hence, it is imperative that the government, along with the private sector, develop programmes to build capacity and interest amongst the country's youth for solving the pressing challenges of the sector and harnessing future opportunities.

The process of digitalisation in addition to offering opportunities to the sector, also poses the possibility of job losses and increasing productivity margins between large-scale and small-holder farmers. Therefore, also proposed **is the development of platforms to encourage commercial farmers to engage in knowledge transfer and the upskilling of small-scale farmers, to ensure they are not left behind in the digitalisation of the sector.** New and advanced technologies should be implemented in an equitable way that prevents, or mitigates, job losses. As mentioned above, commercial farmers have an important role to play in the agriculture sector ecosystem. Apart from incentivising the sharing of agriculture machinery, they need to be encouraged to engage in knowledge transfer and digital upskilling activities for small-holder farmers. While it might be argued that this should be the role of state, the government needs the expertise of the industry leaders to promote the development of the agricultural sector and to counter job losses related to digitalisation. Hence, government's role should be to develop a platform that enables and promotes these transactions.

7.5. Creating opportunities for finance

To ensure an inclusive and rapid uptake of agritech technology**,** the government needs **to improve access to finance for small-scale and emerging farmers by fuelling more funding, engaging with the formal financial sector and harnessing the benefits of alternative finance solutions such as microfinance and crowdfunding, while also creating funding opportunities for local entrepreneurs.** The digitalisation of agriculture will require financial support from both the private and public sector. Government should focus on creating new funding agencies or building the strength of the Land Bank, while the private sector should focus on developing avenues of funding for small-scale and emerging farmers as well as local agritech entrepreneurs. Furthermore, following the successful example of other countries such as Kenya, more can be done to promote alternative finance solutions such as mobile money and crowdfunding initiatives. These can ensure that farmers, especially those previously less visible to the formal financial system, can benefit from innovative insurance and finance products tailored to their needs.

7.6. Harness the potential of PPIs

There is also a need **to develop a national platform and sector-specific guidelines to encourage PPIs as a measure to develop the agriculture sector so that it can achieve its full potential.** The opportunities for PPIs run across the entire value chain and they can also play a pivotal role in the implementation of the other policy recommendations outlined above. As mentioned before, the objective of PPIs should be to promote cooperation, rather than competition. The PPIs will require the collaboration of all stakeholders directly (agriculture value chain) or indirectly related to the agricultural sector (communication, construction, research, education, and manufacturing).

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