DRONES ON THE HORIZON

TRANSFORMING AFRICA'S AGRICULTURE

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The AU was established following the 9th September 1999 Sirte Declaration of the Heads of State and Governments of the Organisation of the African Unity (OAU). The AU is based on a common vision of a united and strong Africa and on the need to build a partnership between governments and all segments of civil society, in particular, women, the youth and the private sector, in order to strengthen solidarity and cohesion amongst the peoples of Africa. As a continental organization, it focuses on the promotion of peace, security and stability. The development work of the AU is guided by the AU Agenda 2063, which is a 50-year plan to harness Africa's comparative advantage to deliver on the vision of "The Africa We Want".

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Acronyms

AU	African Union
AUC	African Union Commission
CIP	Crop Intensification Program
CPA	Conventionally Piloted Aircraft
CTA	Technical Centre for Agricultural and Rural Cooperation ACP-EU
EAC	East African Community
EC	European Commission
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FSD	Swiss Foundation for Mine Action
GIS	Geographical Information Systems
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
IAEA	International Atomic Energy Agency
ICAO	International Civil Aviation Organization
ICT	Information and Communication Technology
IP	Intellectual Property
LAI	Leaf Area Index
NCAA	National Civil Aviation Authority

NDVI	Normalized Difference Vegetation Index
NEPAD	New Partnership for Africa's Development
PPP	Public-Private Partnership
PRI	Photochemical Reflectance Index
PwC	PricewaterhouseCoopers
R&D	Research and Development
RGB	Red, Green, Blue
ROMEO	Remotely Operated Mosquito Emission Operation
RPAS	Remotely Piloted Aircraft Systems
SDGs	Sustainable Development Goals
STISA	Science Technology Innovation Strategy for Africa
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
VTOL	Vertical Take-off and Landing
WFP	World Food Programme

Executive summary

This report provides a contextualized review of drones as a vital precision agriculture-enabling technology and its range of relevant uses for providing detailed and on-demand data in order to enhance decision-making by farmers and hence facilitate much needed support.

Drones for precision agriculture is a farming management concept which is based upon measuring and responding to inter- and intra-field variability in crop and animal production. It is not just the application of new technologies, but rather it is an information revolution that can result in a more precise and effective farm management system. Drones, described as unmanned aerial vehicles (UAVs) or unmanned aerial system (UAS), the latter including the sensor, software, and so forth, have many applications. These include, but are not limited to, land mapping and surveying, land tenure and land use planning, inspection monitoring and surveillance, cargo delivery, scientific research, management of agricultural assets and insurance and crop/infrastructure damage assessment.

In agriculture, there are several major applications of UAS technology, namely crop scouting/monitoring, crop volume and vigour assessments, crop inventory (or the counting of individual plants), generation of prescription maps (such as location-specific nitrogen fertilizer dosage recommendations), precision spraying, inspection of farm infrastructure (including irrigation), high-resolution mapping and surveying of individual fields (such as farm boundary delineations and crop area calculations), crop damage assessment and insurance claim forensics. Drones equipped with adequate sensors have the capability to generate remote-sensing data in near real time in the field rather than the resulting lag in data acquisition from satellite and aircraft-based imagery.

In comparison to satellites, drones can capture very high-resolution imagery under cloud cover and at desired time intervals. It is this increased ease and speed of acquiring the imagery from drones that has the biggest potential for improving how growers respond to much needed crop husbandry interventions. However, drones which tend to be equipped with sensors acquire data, not information. Meanwhile users especially growers, want information that they can interpret and utilize, not data. Hence whatever data is captured by the drones need to be converted into actionable information for farmers.

The deployment of drone technology in Africa has its own challenges, which may be classified under four broad categories; namely technological, economic, social, and legal and regulatory. These include capability, reliability and battery autonomy; commercial batteries for small UAVs allow 24-40 minutes flight fully charged before battery replacement is required. UAV's reliance on communications from a ground operator for control make them vulnerable to signal loss from interference, flying out of range or hacking. While the demand and provision of UAS services is increasing exponentially where crops are grown as monoculture on large holdings, the adoption of UAV technology in the framework of small-scale, multi-crop farming systems in African countries remains a challenge.

More importantly, a skilled workforce is required by the UAV industry whose competences range from planning flight itineraries, piloting UAVs, operating GIS and data analysis software, interpreting data, and providing agronomic or spatial planning advice. There exist social challenges, which span a range of issues including security, the right for privacy, data acquisition, storage and management, causing harm or nuisance to people and animals, damaging property, employment, etc. UAV regulations are still in its infancy in Africa, the making and the presence of too restrictive, or even disabling regulations governing the import and use of

UAVs can hinder the development of a very promising industry, which could attract and engage educated youth in rural areas. In some cases, government agencies or the private sector are already working on solutions that are described in this report.

In conclusion, this report considers drone technology for precision agriculture as a potential game-changer for the African continent. The report recommends that the adoption, deployment and upscaling of UAS in the context of precision agriculture is considered as a priority. Key areas to be considered in upscaling the technology and realising its potential include capacity-building, enabling or supporting infrastructure, regulatory strengthening, research and development and stakeholder engagement. In this regard, the AU High Level Panel recommends the following to the AU organs, member states and Regional Economic Communities (RECs):

At the national level:

- Assess the opportunity cost of UAV technology including external factors and balance it against expected outcomes such as food security, improved health and the potential for drones to make agriculture attractive to the youth.
- Ensure that stakeholders are engaged in all aspects related to the introduction of UAV technology so that potential resistance is understood and dealt with systematically.
- Conduct public awareness around UASs and their civil applications to clearly distinguish between civil and military uses and thereby improve public acceptance. Safety, security and privacy concerns need to be dealt with as part of this process.
- Address cost and technical barriers to adoption through either subsidies, licensed SMEs or cooperatives and build a supportive framework for drone governance and regulation to facilitate adoption (including licensing and registration).
- Encourage and support public-private partnerships for UAV technology uptake.
- Ensure that appropriate national UAV regulations are put in place. Appropriate regulation should strike a balance between competing public security concerns on the one hand and the need to encourage innovation, economic development and youth entrepreneurship on the other. In this context, encourage National Civil Aviation Authorities to establish enabling regulatory frameworks for UAV technology to be deployed and up-scaled to serve precision agriculture.
- Allocate resources for R&D (cost & benefits) and capacity building to build a critical mass in all aspects of drone technology such as licensed pilots, scientists and regulators.
- In the context of smallholder farmers, support crop intensification via stimulating the planting of the same crops simultaneously in contiguous areas to form larger and more rational holdings, which could reap the benefits of UAV technology for precision agriculture.

At the continental level:

- Develop a continental regulatory framework for the use of UAVs in Africa, and harmonize policies across countries and regions (regional economic communities)
- Enhance South-South and regional collaborations, partnerships, networks and knowledge-exchanges to facilitate the upscaling and use of drone technology.

1

Introduction

Agriculture forms the basis for well-being and poverty reduction in Africa. However, with an increase in input costs and uncertainties of weather patterns, a need has risen for countries to adopt farming practices that will increase yields with lowered inputs while optimizing profit. Contrary to being self-sufficient in the 1960's, Africa has currently become a net importer of cereals and other agricultural products. Additionally, the rising population of the continent remains a serious challenge. For example, it is estimated that the current population of 1.25 billion will increase to 2.5 billion by 2050 (Blein & Bwalya, 2013). Hence feeding 2 billion people using existing agricultural interventions will be a difficult task for African countries.

Optimizing agricultural profit through increasing productivity and improved yield has benefitted from several innovative developments over the years; one of these being the use of drones technology. Whilst such interventions, and the green revolution in particular, have benefited many developing countries, this has not been the case in Africa. This situation calls for a review of agricultural policies and practices, and an explicit understanding that enabling policies for the promotion of such drone technologies must be formulated.

Precision agriculture is a way to apply interventions in the right place at the right time (Gebbers & Adamchuk, 2010). It is considered to be a modern farming system, supported by different technologies (Yao & Wu, 2011) that are based on detection of variations in the field and applying each input based on these variations (Robert, 2002). A key feature is the use of global positioning systems (GPS) and timely spatial data that are major enablers of precision. For example, GPS-based applications in precision farming are being used for farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications and yield mapping. GPS also allows farmers to work during low visibility field conditions such as rain, dust, fog and darkness (Zarco-Tejada, 2014).

According to Zarco-Tejada *et al*. (2014), precision agriculture is crucial for the sustainability of agricultural production and minimizing environmental damage, for example, through reduction of nitrate leaking, improved water-use efficiency and increased fuel efficiency. Thus, precision agriculture applies various methods such as geographical information systems (GIS) (Talebpour, Türker, & Yegül, 2015) and remote-sensing, especially temporal and spatially efficient drone-generated data. While GIS techniques have matured in their use for agricultural decision support, the recent entry of flexible, detailed and timely drone-generated spatial data is further enhancing precision agriculture applications. Some of advantages of precision agriculture for commercial and smallholder farmers include the following:

- **Economic benefits:** Through precision agriculture, an area of land within a field may be managed with different input levels depending upon crop yield potential (Ajewole et al., 2016). Therefore, input use on specific areas of the farm can be optimized resulting in increased improved crop production and profit (Godwin, Wood, Taylor, Knight, & Welsh, 2003). However, the cost/benefit analysis of the application of precision agriculture will be dependent on the type of agriculture and nature of the challenge or threat to yield increase.

- **Environmental benefits:** Godwin et al. (2003) indicated that precision agriculture helps to protect the environment from pollution through the use of precise application of pesticides and fertilizers. For instance, the use of variable rate technology in fertilizer application results in less nitrogen loss (Robertson et al., 2007). Thus, farmers can easily conform to legal restrictions on agrochemical use (Stoorvogel & Bouma, 2005). In terms of water-use efficiency, precision agriculture reduces wastage compared to uniform spraying of water or other irrigation systems (Hendriks, 2011).

- **Risk reduction:** Precision farming provides site-specific management that can help identify problems with growing conditions, thereby reducing variability in net returns (Ajewole et al., 2016). For instance, soil and weather information can be used to improve scheduling of operations, which can optimize machinery utilization rates. As a result, pollution risk can be reduced, as well as the cost of producing a crop in a specified area.

In recent times drones have become one of the world's most publicized and intriguing technologies that are used by people in a wide range of professions, from journalism through agriculture to humanitarian aid work. The number of terms used to describe this technology has also risen and often leads to confusion. Therefore, it is useful to understand the various terms that are used. Drone is the most commonly used term, but unmanned aerial vehicle (UAV) and unmanned aerial system (UAS) are also increasingly used. In most cases, the term drone and UAV are considered to be fairly synonymous, while UAS is a reference term that includes the UAV, the ground control station and the system of connecting the two (UAV Insider, 2013).

The relevance of the precision agriculture-drone nexus in enhancing the socio-economic wellbeing of Africa, through improved food production and agricultural methods is specifically indicated in some of the Sustainable Development Goals (SDGs), specifically SDGs 1 and 2, as well as AU Agenda 2063 - ***The Africa we want***, aspirations 1 and 5. It is expected that this AU initiative on emerging technologies will be working in tandem with Pillars 1 and 6 of the Science Technology and Innovation Strategy for Africa (STISA) 2024.

2

A critical analysis of drones in precision agriculture

To evaluate drone technology in Africa, there have been numerous pilot studies, research and exploratory activities. These have attempted to determine sectors where drones can be of immediate benefit to the continent and to also ensure that African countries are primed and ready to embrace this technology as it continues to evolve and offer more potential applications and benefits. (Efron, 2015) (Hardy, Makame, Cross, Majambere, & Msellem, 2017) (Makoye, 2016) (de Klerk, Droogers, Simons, & van Til, 2016) (Look, 2013).

Drones can contribute to the development of the continent as this emerging technology provides a 'leapfrogging' opportunity for Africa. In order to understand drones' full potential for precision agriculture as well as how they can benefit Africa in other ways, it is important to look at the technology in detail and explore its components as well as a range of selected applications.

2.1 Drone types

There is an ever-growing range of UAVs on the market and this is only set to increase, making it extremely important to first evaluate the need for UAVs and then consider the options. In drone selection, initial key considerations should be the flight autonomy, carrying capacity and total weight. All three variables are interdependent; for instance, flight autonomy is often linked to the battery quality and capacity which in turn, impacts on the total weight. The latter is often the starting point for regulatory guidelines, as aircraft weight has a direct correlation with its operational risk. Examples of weight and size classifications are detailed in **Table 1**:

Table 1: Drone classification by size and weight

Class	Maximum gross take-off weight	Size
Micro	<1 kg	No single dimension greater than 50 cm
Mini	1-5 kg	No single dimension greater than 200 cm
Small	5-10 kg	No single dimension greater than 500 cm
Medium	10-25 kg	
Large	>25 kg	

The second important element of choice is its mode of control, which can be summarized as follows:

- **Full manual control:** the pilot has full, unaided control of the aircraft.
- **Aided manual control:** the pilot is in control but is aided by aircraft-mounted sensors, such as accelerometers, tilt sensors or GPS sensors.
- **Partially automated control:** the pilot is typically responsible for setting up the flight, including parameters such as waypoints (an intermediate point or place on a route or line of travel) and speed when launching the drone. But, once the drone is airborne, the autopilot takes over and the pilot is only needed in case of an emergency or a change in flight plan.
- **Fully automated:** once the aircraft is launched, the pilot does not maintain any form of control.

In addition to the control method, UAVs fall into three main categories. The main types are known as multirotor (or multicopter) and fixed wing aircrafts. Fixed wing aircrafts usually have the ability to cover a much larger area than a multirotor, while the latter are easier to pilot and control manually. However, there is a rapidly developing hybrid UAV that has the advantage of the multirotor vertical take-off, whilst also having the flying range and autonomy of a fixed-wing UAV.

2.1.1 Multirotor UAVs

Multirotor UAVs (Figure 1) are currently the most popular drone type and are defined as a UAV that uses three or more blades to achieve lift and movement. Companies like DJI[1] and Parrot[2] have been able to commoditize the multirotor type drones, forcing down the price and thus removing the cost barrier to using UAVs. The simple rotor mechanics utilized by these UAVs have greatly reduced the complexity associated with piloting such craft. With better flight control, multirotor aerial vehicles have been extensively used in applications such as aerial photography and site inspections. One key advantage that multirotors have over fixed wing UAVs is that they have vertical take-off and landing meaning they need very little space to be deployed.

Figure 1: Examples of multirotor UAVs

1 www.dji.com

2 www.parrot.com

2.1.2 Fixed wing UAVs

There are two main types of fixed wing UAVs: the flying wing (Figure 2, left) and the more traditional airplane configuration (Figure 2, right). Fixed wings need considerably more space for take-off and landing compared to multirotors. However, because of their improved flight dynamics, they can cover much larger areas making them ideal for applications such as surveillance, land surveys and large-scale agricultural activities.

Figure 2: Examples of fixed wing UAVs

2.1.3 Vertical take-off and landing (VTOL)

VTOL, or hybrid drones, are a much more recent innovation and take advantage of the multirotor ability for vertical take-off and landing (Figure 3).

Figure 3: Examples of VTOL UAVs

2.2 Emerging civil applications of drones

2.2.1 Land mapping and surveying

UAVs provide a means of leapfrogging from the traditional methods of land surveying because they can provide accurate data for faster decision making. UAVs can be deployed rapidly and allow data generation closer to those that will use it as well as provide a richer dataset of higher resolution and accuracy than using traditional cameras. The data can then be used to generate maps for land use planning, cadastral generation and/or verification, resettlement and so forth (Zanzibar Commision for Lands, 2017). The data generated by these surveys also allows research into how low-cost UAVs can be used to generate advanced flood modelling simulations, therefore replacing the need to use costly and complex manned aircraft. This is demonstrated by Soesilo (2015) in the drone acquisition for mapping and modelling of flood risks in Dar-es-Salaam, Tanzania.

Until the advent of UAS, the acquisition of mapping and survey data was done either via people surveying on the ground, traditional manned aircrafts, or satellite imagery. In the USA and many farms in Europe, GPS and associated technology on tractors are currently used for some of the purposes proposed for drones. One general limitation in UAV mapping is that only those features that are directly depicted on the aerial images can be modelled. Conventional methods are still needed for the modelling of *obscured* features. However, perhaps the most promising aspect of UAV technology is the significant reduction in capital and skills required for data collection and the ability to rapidly deploy to the field and carry out inspections, monitoring and surveillance. With the ever increasing demand on natural resources, the ability to closely monitor and get accurate and timely information on deforestation rates and land degradation for instance, is critical. UAVs offer great opportunities for observing at a distance and documenting evidence at high resolution.

2.2.2 Land tenure and land use planning

UAVs can be used to accelerate the land registration process, facilitating land tenure assessment and titling. Access to land is central for ensuring that the millions of people who live in rural Africa have enough food to eat. Even if people are involved in other trades, land provides an essential safety net during times of economic instability and helps define cultures and identities. The fact that only 10% of rural land is mapped and registered poses a huge hurdle in overcoming some of the basic land tenure insecurities experienced by the majority of the African population, especially rural farming communities. In an urban environment, a UAS can accurately and quickly generate data and high resolution digital elevation models ready for use in land-use planning, verification, corrections or re-alignment of cadastral boundaries, infrastructure development or upgrading.

2.2.3 Cargo delivery

Where road transport is a challenge for small parcels, UAVs offer the opportunity to change the traditional transport system and ensure fast airborne delivery. In Africa, the economics of this type of application are at the time of writing, under review in Madagascar, Malawi and Rwanda (see section 5.4).

2.2.4 Management of agricultural assets

UAS offers a range of exciting opportunities for improving management of agricultural assets. The system provides farmers with a birds-eye-view of their crops, allowing them to detect subtle changes that cannot be readily identified by 'crop scouts' at the ground level. UAVs equipped with specialized sensors are able to collect multispectral images in order to generate crop data such as normalized difference vegetation index (NDVI), leaf area index (LAI) or photochemical reflectance index (PRI) which is a measure of photosynthetic light-use efficiency, thereby allowing users to view crop changes or stress conditions that are otherwise invisible to the human eye.

NDVI provides information about the different biomass levels within a parcel of land. Interpreted NDVI images provide detailed information about water pressure, nutrient deficiencies, pest infestations, crop diseases or other conditions affecting crop development. Imagery indicators such as NDVI, provide a first layer of information that can be added to by information provided from field visits or a dedicated algorithm. For example, algorithms already exist for fertilization where imagery indicators are translated into agronomic indicators to guide application of fertilizer.

The data generated by drones can also be used to speed up the process of conducting crop inventories and yield estimates. Cattle ranchers can also use UAVs to determine the location of their livestock and some have found UAS useful for conducting regular surveys of fencing (Greenwood, 2016). In Africa, there are increasing efforts for improving farmers' opportunities to access credit. The provision of detailed and up-to-date spatially-defined farm data on location, size, standing crops, their health and biomass can help improve farmers' credit-worthiness. The field application of this technology is ongoing in Uganda (Rambaldi G, personal communication 2017).

2.2.5 Scientific research

UAVs are widely used for scientific research. The literature covers a range of UAV uses including archaeological research, measuring contamination, analysing the ash cloud from volcanic eruptions, examining coastal regions, glacier surveillance, identification of plant species or phenotyping, plant or game inventorying, among others.

In the domain of agricultural research, once analyzed and interpreted, the high resolution data collected by the UAV's sensor at desired intervals offer reliable and objective statistics to compare different micro plots at a given crop development stage and to better understand the crop cycle. High resolution (e.g. 1 cm/pixel) remote-sensed data can yield information on absorbed nitrogen, occurrence and distribution of pests, diseases and weeds, water stress, plant density, plant development stages, fresh biomass, dry matter, etc. Depending on the crops, indicators that can be elaborated include the NDVI, LAI, PRI as well as the green normalized difference vegetation index, normalized difference red edge index, total chlorophyll index (Cab; i.e. chlorophyll a and b is used as indicator for the current state of a forest stand and also as an input for various physiological vegetation models), quantity of chlorophyll per area and more.

2.2.6 Insurance and damage assessments

Farmers in developing countries are slowly buying into crop insurance schemes, but delays in insurance pay-outs can cause additional stress for affected communities. In India, the national government has been promoting the establishment of a nationwide insurance scheme supported by UAV technology. The purpose is to ensure rapid assessment and pay-outs of disaster damage, thereby reducing the financial hardship borne by small-scale farmers (Garg, 2016). Large-scale reinsurers, like Munich Re, have partnered with UAV data service providers to enhance insurance assessments worldwide by providing faster response times and increased reporting accuracy in the aftermath of natural disasters (PrecisionHawk, 2016). For the development and humanitarian sectors, the adoption of UAV data services by insurers offers the opportunity for reducing post-disaster hardship among affected communities.

2.3 Complementary technologies

There are several complementary technologies which are common to precision agriculture and the use of drones. These complementary technologies are better understood by looking at the stages involved in the implementation of precision agriculture. Gottard *et al.* (1995) revealed that the concept of precision agriculture has been around since very early in the development of agriculture. However, its practice was facilitated by the development of technology that permitted quantification and differential management of the natural variability of fields.

The emergence of GPS and the Global Navigation Satellite Systems (GNSS) triggered the evolution of modern precision agriculture. The ability of farmers and/or researchers to locate their precise position in a field allows spatial variability maps to be created with as many variables as can be measured (e.g. crop yield, terrain features or topography, organic matter content, moisture levels, nitrogen levels, pH, etc.). The GNSS is made up of a constellation of earth-orbiting satellites around the world including the American GPS, Russian Glonass, Europeans Galileo, Chinese Beidou etc. The satellites transmit accurate time and location information to ground receivers. The location information sent by numerous satellites is received by the ground-receiving units at a specific time so that the exact location can be determined. Availability of accurate location information at a particular point in time allows crop, soil and water measurements to be mapped. GNSS receivers which are either carried to the field or mounted on tractors allow users to return to specific locations to sample or provide appropriate inputs. GNSS-based applications in precision agriculture are being used for various purposes such as farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications, and yield mapping. GNSS further allows farmers to work during low visibility field conditions such as rain, dust, fog and darkness.

Another precision agriculture enabling technology is GIS, which is a tool consisting of a hardware-software database system used to capture, store, retrieve, manipulate, analyze, and display - in map-like form - spatially referenced geographical information. GIS in the simplest terms is the merging of cartography, statistical analysis and database technology. Orellana et al. (2006) state that the ability of GIS to analyze and visualize agricultural environments and workflows has proved to be very beneficial to the farming industry. Boosting a GIS with land-cover data layers has proved helpful to crop growers' associations, crop insurance companies, seed and fertilizer companies, farm chemical companies, libraries, universities, federal and state governments and value-added remote-sensing or GIS companies. Of similar importance to GNSS and GIS in precision agriculture modelling is the use of yield data. These are crop yield measuring devices that are installed on harvesting equipment. From the monitor, yield is properly recorded and stored at regular intervals (of distance or time) together with positional data received from the GPS unit. Other data such as distance and bushels per load, number of loads and fields are also tracked. It is possible to generate yield maps by using GIS software.

Variable rate technology is another modelling tool which integrates farm field equipment with the capacity to precisely control tillage operations and the application rate of crop inputs. Variable rate controllers are available for granular, liquid and gaseous fertilizer or agrochemical materials which enables farmers to add the quantity of crop inputs needed at a precise field location according to the individual characteristics or requirements of that location.

Last but not least is remote sensing data. Image data generated by remote sensing from soil and crops is processed and added to a GIS database. There are three sources of remote-sensing data commonly used in agriculture, namely: (i) proximal sensors; (ii) airborne sensors; and (iii) satellite sensors. Proximal hand-held sensors example, for measuring chlorophyll fluorescence, are mainly used for basic research. Data obtained by this kind of sensor is used to establish relationships between spectral behaviour and biophysical parameters of crops under certain stress (nutritional, thermal and water). In aggregate, these field data are transformed into vegetation indexes that are then related to agronomical parameters, including foliar area index, productivity and biomass amongst others. Various studies have shown that physical features, such as soil organic matter content, texture and permeability may be correlated with the spectral response recorded by remote-sensing images (Leone et al., 1995); (Thompson & Robert, 1994). Thermal temperatures (obtained from thermal images) have also been used to study water content and soil compaction. The most widely used remote sensing-derived tool is NDVI, which has been related to different crop variables (mainly yield) and has been used to identify variability in field conditions.

2.4 Maturity and readiness for implementation

2.4.1 Market demand

Drone technologies are considered emerging, and are thus are quite novel, especially in Africa. The readiness with which drone technologies can be applied to farm production challenges will depend on the demand (pull) for drone technology and the prevailing barriers to accessing the technology in terms of cost, infrastructure and trained manpower, amongst others. In crisis situations, many African countries will not hesitate to use drones when exposed to the technology for determining for example, flood prone areas in Tanzania (Soesilo & Bergtora Sandvik, 2016) and cargo delivery of blood for medical purposes in Rwanda (Rwanda Biomedical Center, 2016).

In recent times, numerous African countries have encountered a rapid infestation of Fall Armyworms in maize production that have ravaged about 200,000 ha of farmland in Ghana, for example. The extent of crop devastation and progression of infestation are not currently known so that effective control can be instituted. The use of remote-sensing facilities like drones (currently not in place) may allow determination of the extent and progression of infestation in order to put in place effective control practices.

2.4.2 Status of regulations and infrastructure

About 26% of all African countries have UAV regulations in place (https://www.droneregulations.info). Some other countries have made minor changes to existing regulations and the rest are either in the process of developing regulations for UAVs or have taken no action (See section 4.2). In addition, the required infrastructure to support drone use and training on piloting and use of drone data should be promoted. Mauritius, Morocco, Rwanda, South Africa and Tanzania are among the countries where UAVs are currently deployed for crop scouting purposes but widespread use of drones in agriculture is yet to be adopted across the continent.

3

Drone implementation in Africa

Drones have been implemented in Africa at both national and regional levels as detailed below:

3.1 Implementation at national level

3.1.1 Land use planning and land tenure

3.1.1.1 Tanzania land tenure

In 2016, the Ministry of Lands in Tanzania conducted a project to evaluate UASs as an option for acquiring aerial imagery to support a national land tenure programme. The objective of the mission was to determine if UASs are a viable alternative to manned aircraft and satellite as a source of aerial imagery. A pilot study was conducted and its results were extremely encouraging. The primary objective was to fly over a distance of 24 km2. This was exceeded, as a total area of 147 km2 was surveyed instead and a ground sampling distance of 7 cm achieved. A secondary objective which was to determine possible absolute accuracy was also achieved with ground control points. The Ministry of Lands confirmed absolute accuracy within 2 cm. The work in Tanzania has stimulated much interest both within Africa and internationally in the use of UASs for land tenure systems (Makoye, 2016).

3.1.1.2 Zanzibar mapping initiative

In November 2016, the Commission for Lands in Zanzibar together with multiple partners, undertook a project to map the whole of Zanzibar using small-scale drones, with the result that 80% of Zanzibar's land area was mapped. Although the project is not yet completed, 15 students and 4 government surveyors have already been trained and 20 drone operating certificates issued to students and government surveyors (Zanzibar Commission for Lands, 2017).

3.1.2 Small-scale farming and agribusiness

3.1.2.1 UAS supporting small-scale farmers in Mozambique

In the wake of climate change, many farmers are confronted with limited actionable information on where and when to apply available resources such as water, fertilizer and seed. In Mozambique, an intervention is proving that advice provided by extension workers who have been using low-cost drones, has helped farmers make informed decisions for improving crop water efficiency and yields. The Third Eye project, uses recreational drones equipped with near-infrared sensors and tailored software to locally capture and analyze data. Resulting information is visualized in map form and discussed with farmers who grow beans, maize and rice. The project area is 1,800 ha and involves 2,800 farmers, 71% of whom are women. A total of 14 extension workers have been trained to operate the drones and capture, analyze and present findings to the farmers. Data gathered during project implementation indicates that crop production had increased by 41%, while total water use was reduced by 9%, resulting in a 55% water productivity increase.

3.1.2.2 UAS services supporting agribusiness in Morocco

In Morocco, UAS services are used to help ensure that there is an efficient application of fertilizers to meet the desired quality of crops. Les Domaines Agricoles, the largest Moroccan agribusiness, has adopted UAS and agronomic analytics to increase fertilizer effectiveness and has reported positive outcomes in terms of yield and product quality. The crops they grow include citrus fruits and aromatic plants, among others.

3.1.3 Humanitarian and emergency relief

3.1.3.1 Flood mapping for disaster risk reduction

With an estimated population of 5 million, and an annual growth rate of 8%, Dar-es-Salaam in Tanzania, is one of Africa's fastest growing cities. Over 70% of the population live in informal, unplanned settlements with inadequate infrastructure. In addition, heavy rainfall twice a year results in significant flood risks. In 2015, a consortium comprising local authorities, the Tanzania Commission for Science and Technology, two universities and the Buni Innovation Hub led the production of a detailed map of the city. Aerial imagery at 5 cm resolution and covering an area of 88 km2, was captured over a period of 2 weeks by using fixed wing UAVs. At present, the map is used for urban planning with a particular emphasis on disaster risk reduction and preparedness for natural calamities such as floods, as well as health emergencies such as cholera (Soesilo et al., 2016)

3.1.4 Surveillance and monitoring

3.1.4.1 Surveying port facilities in Morocco

Drones are used to survey Casablanca port facilities and monitor ongoing construction. Regular flights are organized over the port to ensure contractors meet their deadlines. High-definition images which are captured by air-borne sensors, are used by port officials for monitoring and eventually seeking further information or launching investigations about the progress of ongoing construction. A multirotor drone flying at a low altitude provides a 3D model that is very useful in terms of topographic information.

3.1.5 Wildlife monitoring and protection

In Africa, protected areas are facing severe challenges. Protected wildlife species are threatened by illegal activities such as poaching. Although UAV deployment in this context is still new, a few initiatives are worth mentioning. UASs have been used to survey large mammals in Burkina Faso (Vermeulen et al., 2013). UASs are also used in South Africa's Kruger National Park to fight against rhino poaching (Mulero-Pázmány *et al.,* 2014). The Namibian government, through the Namibian defence force, supports rhino and elephant anti-poaching programmes using UAS (Nkala, 2014). In addition, Conservation Drone, one of the major players in the use of drones for conservation, conducted a mission with UAVs in the Loango National Park in Gabon and the Tchimpounga Nature Reserve in Congo (Sweeney, 2015).

The use of UASs to monitor illegal or unsustainable uses of forest resources and land occupancy in general has been initiated in many parts of the world. International and national non-governmental organisations have been eager adopters of the technology to empower marginalized communities and indigenous peoples to gather visual evidence of illegal activities by using an 'eye in the sky' (UAV). While there are no documented cases for this UAS application in Africa, examples are known in Asia and Latin America.

3.1.6 Cargo delivery

3.1.6.1 Delivery of health care items

In 2016, the Government of Rwanda partnered with a USA-based robotics company Zipline to launch a delivery programme aimed at reducing the delivery time of blood (Rwanda Biomedical Center, 2016). In 2017, they were able to achieve this by cutting the medical facility's time to procure blood from four hours to 15-minutes (Rosen, 2017).

3.1.6.2 Dispersal of sterile insects for biological control of pests and diseases

Jointly developed by the International Atomic Energy Agency (IAEA), the Food and Agriculture Organization of the United Nations (FAO), and built by a German drone manufacturer, the UAV used in the Remotely Operated Mosquito Emission Operation (ROMEO) enabled transport and dispersal of sterile male mosquitoes to provide biological control of mosquitoes which may be the vector of serious diseases (FAO/IAEA, 2016). A similar initiative has been supported by IAEA in Ethiopia to disperse sterile male Tsetse flies (Atherton, 2016).

3.2 Implementation at regional level

UAV use is still in its infancy in Africa and there is little in the literature regarding regional projects and initiatives using drone technology. This is likely to be linked to the fact that UAV governance is handled at national level and the rules and regulations that apply to UAV use are issued by National Civil Aviation Authorities (NCAAs) and hence differ across regions. The lack of regional initiatives in Africa mirrors global developments where military drone technology is mostly discussed in relation to peace and security. In Europe, the EC is spearheading an effort to harmonize national UAV regulations through the creation of an EU-wide framework. The harmonization of regulations could be implemented by African countries when drones are widely adopted.

4

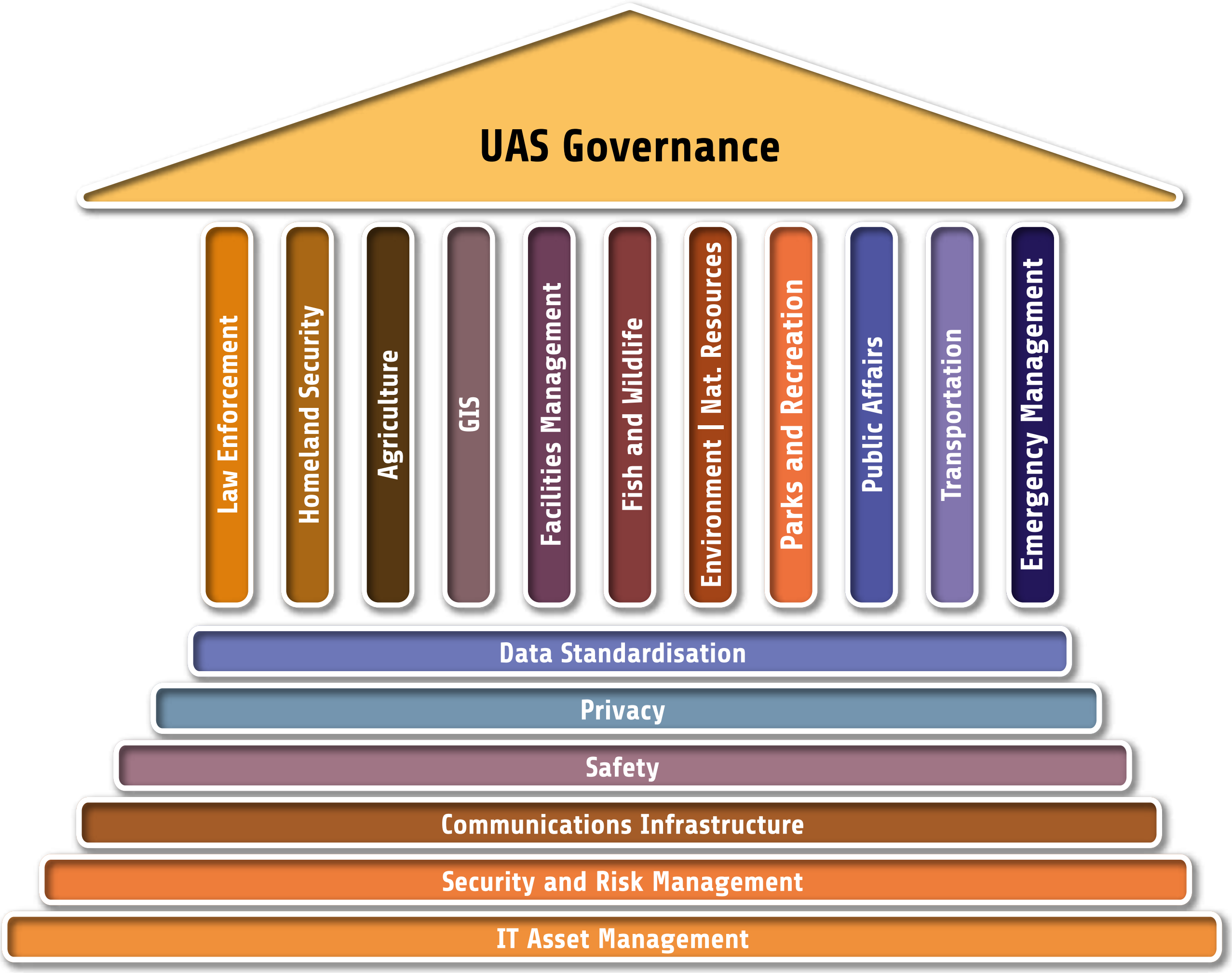
Public policy and regulatory systems

4.1 Governance

In UAVs governance is a multi-sectorial issue which must involve all relevant actors in decision-making. For the most part, however, the regulation of civilian airspace will remain the responsibility of the relevant National Civil Aviation Authority (NCAA), which is in control of both the development and enactment of the regulations and their enforcement. The diagram below, taken from a paper published by NASIO, Estes et al. (2015) exemplifies the ideal building blocks and flow for the development of a UAV governance strategy 4.

The horizontal pillars in the diagram illustrate how a UAS governance strategy should be built on a solid foundation. This comprises of policies that take into account issues such as public privacy and safety, enforce data exchange and communications standards, and include agreed methods for managing and mitigating risks. The vertical pillars represent the various sectors or areas of operations using UAVs.

Figure 4: Governance architecture for UAS



4.2 Policies and regulations

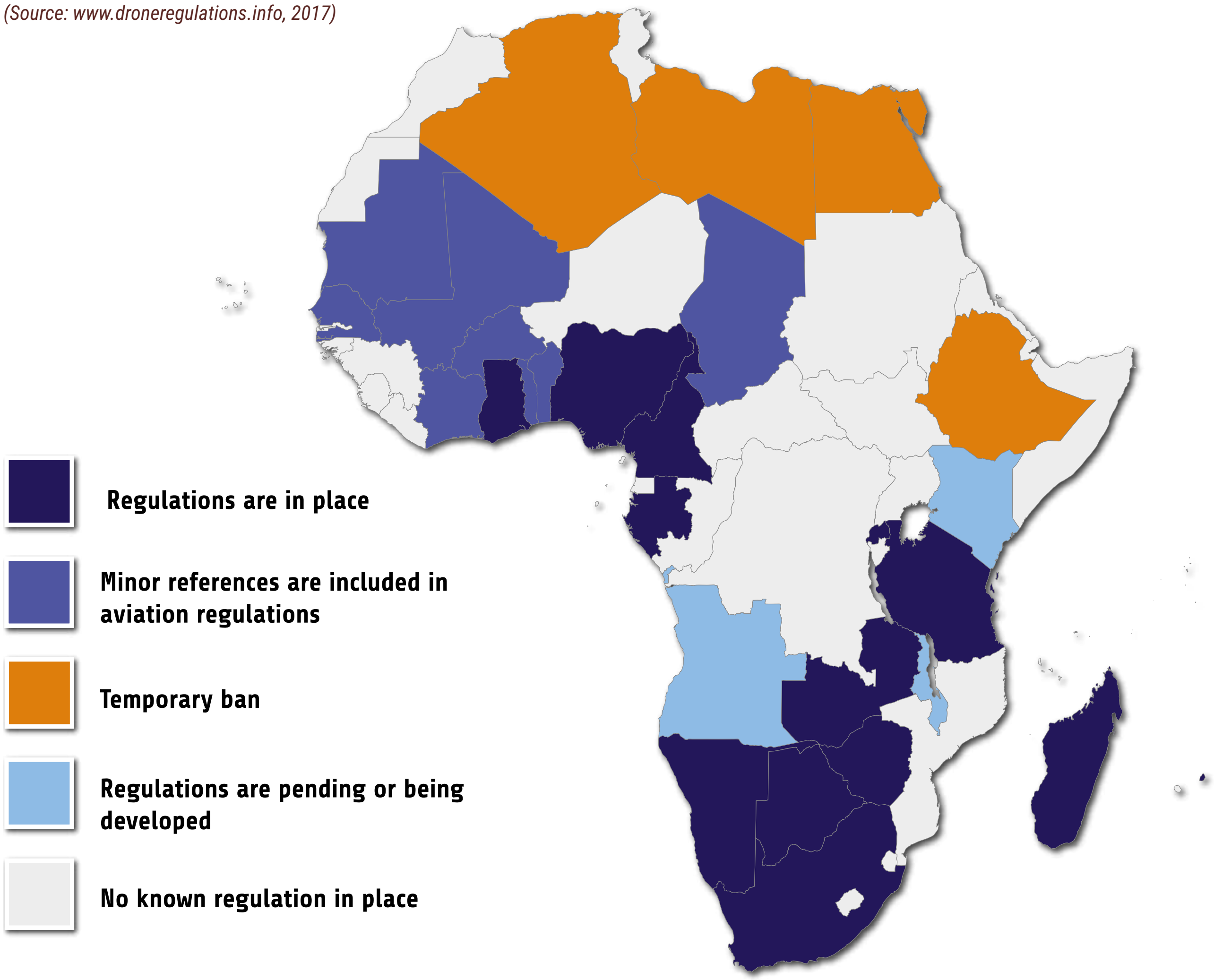
In each country the NCAA are the governments' statutory authorities that oversee the approval and regulation of civil aviation. NCAAs are also the primary regulator of UAV usage within the national airspace. NCAAs typically regulate critical aspects of large manned aircraft, their airworthiness and their operations. Regulating the use of UAVs, especially small-to medium ones, which recently appeared on the market has been an added responsibility in unchartered territory. Wherever UAV regulations are in place, NCAAs are generally responsible for the following *vis-à-vis* UAV use: (i) checking on airborne and ground-based equipment affecting flight safety; (ii) pilot licensing; (iii) issuing flight permits; (iv) defining standards for UAV operations and minimum requirements for operating different UAV classes based on take-off mass and size.

On its website, the International Civil Aviation Organization (ICAO) offers a UAV toolkit with a small collection of current national UAV regulations (ICAO, 2017). Unfortunately, no African country is included on the ICAO database. The status of UAV regulations in Africa can be obtained from the Global Drone Regulations Database (https://www.droneregulations.info).

South Africa was the first country to implement and enforce a comprehensive set of legally-binding rules governing UAVs in July 2015. As shown in Figure 5, a total of 14 African countries published dedicated UAV regulations in July 2017, which represents 26% of the total number of countries on the continent. Seven countries, under 'minor references', appended early ICAO guidance to their aviation regulations. It is noteworthy that the guidance is entirely replicated suggesting standardisation of the regulations has already been a factor in Africa (Rambaldi & Guerin, 2017).

Figure 5: Status of UAV regulations in Africa

(Source: www.droneregulations.info, 2017)



5

Challenges and forthcoming solutions

UAV deployment has its own challenges which may be classified under four broad categories: technological, economic, social and legal and regulatory as suggested by Clothier *et al.* (2015). In some cases government agencies and private sector operators are already working on solutions which are described below.

5.1 Technology

Solutions that the industry is working on include autonomy, capability and reliability. Battery autonomy is one of the key challenges for UAV operators. Commercial batteries for small UAVs allow 24-40 minutes flight fully charged before battery replacement is required. Fixed wing UAVs have a longer battery autonomy compared to multirotors. Some companies which offer solar-powered UAVs claim that these can fly for hours. As with electricity-powered cars, the development of high capacity, fast-loading batteries to enable increased UAV flight autonomy is considered a top priority by UAV manufacturers and huge investments are being made to find solutions.

Lithium batteries, which are the most widely used for powering UAVs, have their own challenges as they can generate a great amount of heat if short-circuited, or may catch fire if damaged, poorly designed or improperly assembled. In fact transport of lithium batteries exceeding a set amount of watt-hours is considered a hazard by many commercial airlines. Strict rules are enforced to minimize risks inherent to the transport of such batteries on commercial passenger planes.

UAV's reliance on communications from a ground operator for control make them vulnerable to signal loss from interference, blanking, flying out of range or hacking. When a UAV loses the signal that is guiding it, the vehicle has to decide what to do although UAVs are usually programmed to handle these situations. The challenge of safely manoeuvring a UAV beyond the line of sight has been recently addressed by the development and installation of technology. This enables UAVs to 'detect and avoid' other stationary or moving objects. However, the challenge remains for all drones which are currently on the market that are not equipped with detect-and-avoid technology.

Increasingly, UAVs are equipped with geo-fencing software, which prevents flying within restricted areas or provides a warning to the pilot if the UAV enters a sensitive no-fly zone. Automatic updates with temporary flight restrictions around wildfires, for example, help protect authorized firefighting aircraft and ensure fire crews can operate without disruption. Software such as the Geospatial Environment Online includes permanent flight restrictions around prisons, nuclear power plants and other sensitive locations, as well as temporary restrictions for large stadium gatherings and national security events. The software also introduces flexibility to drone pilots by giving them the ability to unlock some restricted areas where they have permission to operate (DJI, 2016).

While geo-fencing software is currently available, the main challenge in Africa is in NCAAs making relevant data (e.g. no-fly zones) regularly available to the drone manufacturers or dedicated service providers for distribution through software updates to the operators.

5.2 Economic

While the demand and provision of UAS services is increasing exponentially in Australia, the USA and some European countries, where crops are grown as monoculture on large holdings, the adoption of UAV technology in the framework of small-scale, multi-crop farming systems in African countries remains a challenge. While cost/benefit of UAV technology and the willingness for African farmers to pay has still to be assessed, large-scale agribusinesses have already embraced the technology in countries such as Mauritius, Morocco, South Africa, and Sudan, amongst others. In the context of smallholdings, UAS services are likely to

be affordable to farmers who are part of large cooperatives growing the same crop on contiguous areas. This concept has been successfully put into practice for farm mechanization in Rwanda in the framework of the national Crop Intensification Program (CIP), where farmers synchronize the cultivation of crops on consolidated lands, which are rearranged to form larger and more rational holdings (Kathiresan, 2011).

There is scientific evidence that location-specific action taken based on UAS-generated data improves farm productivity or results in savings in terms of agricultural inputs. However, the lack of large-scale UAS operations in Africa results in insufficient scientific evidence that shows how benefits accruing to a farmer would outweigh the UAS costs. In order to address this shortcoming on-field some research has started, while others are in the process of starting in several African countries.

As the UAS service industry is still in its infancy on the African continent, there are few licensed operators to deliver services in the agricultural sector. South Africa has the highest number of licensed commercial UAS service providers. Nonetheless, their absolute number (14) (Wijnberg, 2017) is low compared to the UK where, as of July 31 2017, there were a total of 3,026 active and approved small UAV operators deploying 7 kg UAVs and/or 7-20 kg UAVs (Civil Aviation Authority (UK), 2017). Consequently, the challenge of finding a UAS service provider may turn into opportunities for educated youths interested in developing a UAV enterprise.

A UAV equipped with a sensor is a part of the equation. UAS operations generate a huge amount of data, which need adequate storage space and computing power to be processed. Hence, complementary investments could include robust and large data storage facilities, data analysis software and high computing power for running it, fast internet connectivity and accessible power supply, if data analysis is carried out in the cloud. In addition and more importantly, a skilled workforce is required by the UAV industry whose competences range from planning flight itineraries, piloting UAVs, operating GIS and data analysis software, interpreting data and providing agronomic or spatial planning advice.

5.3 Legal and regulatory

Small UAVs are unmistakably different from aircraft in so many ways, yet they are considered as fully-fledged aircraft in most countries, which is perhaps the primary challenge impacting their governance. Few predicted how the UAV industry would reinvent itself so dramatically and become so far reaching in every enterprise and field of work. (Rambaldi & Guerin, 2017). The number of UAS now flying in Australia, EU and the USA is in the millions and recent studies indicate that they will increase exponentially across the globe.

According to PricewaterhouseCoopers (PwC), UAS will transform agriculture into a high-tech industry with decisions being based on real-time gathering and processing of data resulting in an increase in productivity and yields (Drone Powered Solutions, 2016). As a new technology, UAS is evolving faster than the regulations intended to govern its use. Hence, the development and systematic updating of a regulatory framework fit for all, is a daunting challenge for all responsible authorities.

In Africa, as exemplified in section 4.2, UAV regulations are still in the making and the presence of too restrictive, or even disabling regulations governing the import and use of UAVs hinders the development of a very promising industry, which could attract and engage educated youth in rural areas. Some countries have resorted to temporary bans on import and use of UAS awaiting regulations to be put in place and, consequently, UAVs are confiscated from travellers at the port of entry (Rambaldi & Guerin, 2017). Those attempting to obtain an import permit for running UAS services have to deal with a range of government bodies, including the Ministry of Agriculture Animal Industry and Fisheries, Ministry of Internal Affairs, Ministry of Defence, Civil Aviation Authority and more, without having the certitude to obtain the needed permit.

South Africa has regulations in place, but it appears that these pose some challenges to the development of a thriving UAS service industry. According to a licensed UAS operator (Wijnberg L. , 2017) the heavy-handed approach has forced some UAS companies to either operate outside the framework of the law, or operate in neighbouring countries in order to stay in business. In South Africa, the regulations consider that using an UAS for agricultural data-generation means that UAS are used commercially and should be governed in the same manner as commercial manned aircraft. This requires the operator to comply with a number of key steps, including, but not limited to, the following: (i) obtaining a remote pilot license; (ii) registering the aircraft; and (iii) obtaining an air service license (ASL) from the Department of Transport and obtaining a remote operator's certificate (ROC) from the South African Civil Aviation Authority. A single person cannot comply with all the requirements, as these require a number of positions to be filled, such as quality assurance manager, flight operations manager, safety officer, and security officer, amongst others. The total cost to comply with the regulations exceeds R500, 000 (US$38,700) and takes over two years to complete. Often, some sections, such as the ASL, will expire and require renewal before the ROC is issued. Since the regulations were published in 2015, only 14 companies have been licensed to operate, with a backlog of over 400 applications (Wijnberg L. , 2017).

The **Kenya** Civil Aviation Authority announced the development of its national regulations governing the use of remotely piloted aircraft in February 2017. At the time of writing this report, such regulations have still to be enacted and the import and use of UAVs is prohibited. Several development agencies and international research institutions interested in supporting the introduction and use of UAS in the agricultural sector are facing a legal void and have put projects on hold or cancelled allocated funds.

The **Rwanda** Civil Aviation Authority enacted its UAS regulations in June 2016 but has issued only one permit to a local company so far.

The **Ghana** Civil Aviation Authority enacted its regulations in June 2016. In December 2016, it issued an additional directive instructing all UAV operators or users to obtain written permission from regional or local police stations before operating UAVs. The enabling environment favoured the industry and a number of UAS operators already service the agricultural sector.

In **Nigeria**, in May 2016, the government banned the unlicensed use of UAVs and stipulated guidelines for drone operators in Nigeria. The guidelines require UAV operators to: (i) pay an initial non-refundable deposit of N500,000 (US$1,390) and an additional annual renewal fee of N100,000 (US$278); (ii) command a minimum share capital of N20 million (US$55,600; (iii) obtain security clearance from the National Security Agency; and (iv) submit a request for authorization to fly at least 6 months prior to intended UAV use (Adewopo, 2017). Although tough and selective, these requirements were met by a number of companies. The Nigerian Civil Aviation Authority issued its first UAV operator certificate in June 2017 (NCAA, 2017) and plans to set up an online portal for allowing the registration of all UAV users in the country.

The above-summarized cases point to lack of harmonization of UAV regulations across African countries. To address this phenomenon, through its regional Eastern, Southern, Western and Central African offices, ICAO organises working groups and events to share knowledge and experiences to enable benchmarking and harmonizing of regulatory requirements, procedures and guidance material under the spearheading of selected States, which have made significant progress in this area.

5.4 Social

Social challenges overlap with technological and economic challenges, and concern both UAV manufacturers as well as operators. The challenges span a range of issues including security, the right for privacy, data acquisition, storage and management causing harm or nuisance to people and animals, damaging property and employment.

For example, UAVs must be built and operated to be as quiet as possible, designed to minimize emissions, potentially include detect and avoid technology, and be receptive of geo-fencing instructions. Operators should be aware of surrounding ecosystems and any regulations to protect these. Wild and domesticated animals react to nearby flying UAV and may get scared and stressed. Increasingly, the recreational use of UAVs in national parks is prohibited.

With their ability to covertly capture high-resolution imagery and video, drones pose new challenges with regards to privacy and data protection. Very few African countries have comprehensive domestic legislation on privacy and data protection and information storage (Look, 2013). There are also valid individual privacy issues, as people may be recorded going to places or doing things they want to keep private, their illegal businesses or structures may become visible or they may simply be uncomfortable being photographed or mapped (Gilman, 2015).

In terms of employment, one could argue that UAVs could affect the employment of those tasked with monitoring natural resources, crops and assets. The reality is that there are fewer people willing to engage in arduous tasks involving patrolling, scouting and inspecting assets in remote and poorly served locations. On the other hand, there are many young graduates captivated by emerging technologies who are interested in engaging in UAV-related activities. When it comes to deploying UAS for precision-agriculture, the link to rural areas is more than obvious; the widespread adoption of the technology could help retain youth in rural areas to act as UAV pilots, data analysts or agronomic advisors. UAS adoption can generate employment among educated youth and create an exciting high-tech environment for agro-entrepreneurs, thus stimulating the youth to engage in the agricultural sector.

Potential aircraft collisions, personal injury and property damage are perceived as the main safety concerns by the public, national and international governing bodies. Significant research is being undertaken to model and assess these risks and, based on the research findings, to inform the development of regulations to ensure they are appropriately managed. Guiding the development of UAV safety regulations is a high-level safety objective. The European Remotely Piloted Aircraft Systems (RPAS) Steering Group and the Drone Advisory Committee in the USA are strong steering groups who have influenced the acceptance of a risk-based approach to UAVs' integration into the airspace system. Risk increases progressively with the increase in UAV weight and size, the complexity of the operation (e.g. night time), location (remote, urban, high capacity airspace) and has to be balanced by a range of mitigations, on a case by case basis. The European Aviation Safety Agency (EASA) uses a three-tiered approach to risk which at the low risk end, begins with the 'open' category which is limited to low-altitude, visual line of sight, away from crowds and infrastructure, and below 25 kg, which includes most UAVs used in precision agriculture. As risk increases, an operational risk assessment of each operation must be conducted, and this is assessed by the NCAA or a qualified entity for approval under the 'specific' category. The most widely adopted qualification of the high-level safety objective is equivalent to the safety performance of conventionally piloted aircraft (CPA). Specifically, drones must exhibit at least an equivalent level of safety to CPA operations. Efforts to quantify the safety objective are largely based on historical CPA accident data.

In addition to developing and enacting UAV regulations, NCAAs are in the process of developing and publicising UAV no-fly zones. Existing national regulations also oblige commercial operators to insure their UAV against personal injury and property damage. In addition, UAV manufacturers are increasingly equipping aircrafts with collision avoidance technology and geo-fencing (virtual perimeter) systems. Where UAV regulations are in place, commercial UAV operators are mandated to have a third party liability insurance covering potential damage caused by the airborne equipment.

A few years ago, due to the lack of market, most insurance brokers were not in a position to offer such coverage. Those who did offer coverage asked for very high premiums. At present, a number of African insurance companies offer UAV third party liability coverage, either as a self-standing product or integrated within other offerings. The challenge persists in countries where no regulations are in place or where recreational users do not assume their responsibilities and fly drones without adequate insurance cover. Once UAV use is made legal in a country, governments need to raise awareness among the population that UAVs exceeding 250 g, for example, can cause harm like other vehicles and adequate precautions need to be taken by owners.

A recent study conducted in Tanzania by the non-profit organization, FHI360 (Eichleay *et al.* (2016)) found that for the most part, the public perception of drones was fairly positive. FHI360 conducted interviews with ordinary citizens and with a number of government officials, including those who had observed drones operations and those who had not. The study provided the following findings: "*The majority (78%) of the witnesses had no concerns about the use of drones in their communities. Those who did express concerns mentioned accidents (22%); security, including use for bombing or criminal activities (20%); and visual privacy (12%). A quarter of the witnesses expressed non-specific concerns.*" All officials expressed some degree of concern. The most commonly reported concerns were related to costs and regulations. All officials recognized the need to regulate and control drones if they were to be used in Tanzania. As one government official stated, *"For me, as long as the reason for flying is known, then I have no problem."* (Eichleay *et al.,* 2016).

In early 2016, the Swiss Foundation for Mine Action (FSD) undertook a survey aimed at measuring perceptions of UAV use in humanitarian action. The survey was distributed in English, French and Spanish to humanitarian professionals working in 61 countries. Of the 194 responses received, most came from humanitarian NGOs (52%), followed by donors (19%), and United Nations agencies (10%). Based on the results, the overall perception was generally favourable or very favourable (61%). Humanitarian professionals expressed confidence that UAVs have the potential to strengthen humanitarian work, and that UAVs can greatly enhance the speed and quality of localized needs' assessments. Still, a significant minority (22%) viewed drone use in humanitarian work unfavourably. Importantly, only approximately one in ten respondents had actual experience with drones in humanitarian settings. The reasons cited for a negative perception fall into three general categories: (i) concerns that the technology creates distance between beneficiaries and aid workers; (ii) the potential association with military applications; and (iii) the lack of added value delivered by drone use (Soesilo & Bergtora Sandvik, 2016).

Risk assessment is one of the many factors influencing public acceptance of an emerging technology. In the context of UAVs, the broader issues of privacy, security, liability and ethics associated with their use are likely to be influential in the widespread acceptance of the technology. In an increasingly risk-aware society, there is a need to better understand public perceptions and concerns relating to emerging technologies prior to their widespread uptake. There is therefore, a need for the following to be done: (a) conduct additional perception surveys; (b) seek support from development agencies for the deployment of the technology; and (c) engage social media and closely coordinate with traditional media as these channels are ultimately going to influence public perception.

Social acceptance of UAV technology may be enhanced if benefits deriving from the deployment of the technology go beyond serving precision agriculture. A case in point is the use of cargo UAVs to deliver medical supplies and blood samples as is currently happening in Madagascar, Rwanda, and Tanzania. In this context, investors led by the Norman Foster Foundation, plan to develop a drone port in Rwanda, which would be in a position to support cargo drone routes capable of delivering urgent supplies to remote areas on a massive scale.

6

Opportunities for leapfrogging

6.1 Public-private partnerships (PPPs)

The use of drones for precision agriculture has mostly been driven by drone manufacturers including Precision Hawk, AgEagle, Sentera, Agribotix, senseFly, DJI, and Parrot, amongst others, and companies offering data analysis platforms or software (AIRINOV, DroneDeploy, Pix4D, Agisoft, etc.) in conjunction with many tertiary institutions and agri-research institutes. Drones are often hailed as transformative technologies and PPPs could represent an avenue for addressing some of the challenges associated with the introduction and upscaling of UAV technology in African countries. The partnership of the Rwandan Government with Zipline is a good PPP example (see section 3.1.6.1). Drones and other emerging technologies only have viable futures if there is a market for them. If there is no market for a technology then companies do not have an incentive to develop and sell them.

6.2 Research and development (R&D)

Most of the drone research and development focus areas have been in areas such as crop health and yield improvement, crop damage assessment, irrigation management, cattle herd monitoring, and variable rate technology in applying inputs. These research areas are closely related to solving farmers' need within the context of local agricultural systems. However, there are some challenges which include the local specificities of African farmers such as small per capita land holdings, heterogeneous cropping and land tenure issues and the diversity of agricultural systems. Hence there is a need to conduct research and development activities to assess which interventions are suitable for UAV technology to be cost-effective from a smallholder perspective. The reluctance of farmers to quickly embrace emerging technologies is known and to some extent justified.

Thorough research has to be conducted to assess how far UAS can be a catalyst in the adoption and upscaling of precision agriculture and crop intensification, especially in the context of smallholder farming. UAV adoption will also rely on at least a marginal return on investment for farmers and UAV operators. The microeconomics of this technology with respect to research and development will need to be well understood and documented. In addition, the integration of research and development into UAV technology and existing local governance structures should be properly examined as a model for the technology's introduction and sustainability.

6.3 Capacity building and the emergence of new enterprises

When it comes to precision agriculture, farmers often do not need raw data but actionable information to support their decision-making processes. In this context, the emergence of technology intermediaries who can provide UAS-based advisory services is critical and is at the same time beneficial in terms of job creation for educated youth in rural areas. Capacity building of UAV pilots, farmers, relevant stakeholders and the incorporation of GIS remote-sensing experts and agronomists, will offer optimal teams for quality UAV service delivery.

6.4 Intellectual property (IP)

IP frameworks need strengthening in Africa. Weak IP structures coupled with limited awareness, renders African innovation susceptible to 'hijacking' by global players. While no specific IP cases have yet been documented in UAV technology, there are reported incidences of young innovators who have been cheated out of benefiting from their inventions or innovations. Legal liability for drone usage may rest on either the inventor, the controller or the IP holder. As such there must be controls on who can create, own or use a drone since any infringement enacted by or through the drone will be attributable to one of these.

Drones are also subject to 'patent trolls' who buy patents with the intent of defrauding entities that have a legal and legitimate interest in the technology. With drones, patent trolls can deviate from the intended use of a patent holder and enable the technology to be used in abusive or malicious ways. With the emergence of this new UAV industry and the likelihood of the development of crop-specific advisory solutions which could have global relevance, governments should take the opportunity to strengthen national IP frameworks, related legislation and governance structures.

6.5 Increased interest shown by development agencies

There is an increased interest by international bodies and development agencies in testing and supporting the adoption of UAV technology.

As previously stated, the EC considers, *"Drone technologies are a unique opportunity for the European economy to generate additional growth and prosperity: they open the door to new markets for innovative services with immense potential"* (EC, 2016). The World Bank has been supporting the adoption of drone technology to address disaster risk reduction in some countries (e.g. Tanzania). USAID has been pilot-testing drone use in agriculture in Mozambique and Rwanda. In Rwanda for example, USAID has partnered with AgriLift to pilot the drone-based crop monitoring technology. The drone takes overhead images of growing crops at specific intervals. The images are then analyzed with an open-source computer model of plant growth, which was specifically developed for potato farms. The drone technology can identify the optimal maturity of potato plants for farmers, and can also spot nutrient deficient or diseased crops.

The United Nation's World Food Programme (WFP) and the Government of Belgium have launched an initiative to explore UAV use in humanitarian emergencies (WFP, 2017). The UN Children's Fund (UNICEF) has pilot tested drone use in Malawi and suggests that, "this technology has a potential to extend not just for health but also for farming, emergencies, and other humanitarian needs" (UNICEF, 2016). The Rockefeller Foundation and the Technical Centre for Agricultural and Rural Cooperation ACP-EU (CTA) are supporting humanitarian and agriculture UAV start-ups, respectively.

6.6 Decreasing technology costs

As with computers, smartphones and other technological devices, the price of UAVs and ancillary equipment like sensors have been progressively decreasing while their performance like flight autonomy, manoeuvrability, and programmability etc., have been increasing.

6.7 High demand for timely actionable information

While UAVs are unlikely to entirely replace manned aircraft or satellite earth observation systems, they have several advantages over more traditional remote-sensing devices. UAVs can collect extremely high-resolution imagery (up to a few cm^2 per pixel) below the cloud level, which offers much more detail than the satellite imagery usually available to users in developing countries.

UAVs are relatively easy to use as most mapping and data-collection missions can be programmed. This means that the aircraft flies according to a pre-programmed path and at a set altitude. Compared with satellites which cover a given portion of the earth at regular intervals, UAVs can be flown at any time provided that weather conditions are favourable (no rain or strong wind) and complies with national regulations. Private sector enterprises in diverse sectors are increasingly considering UAV-based technology and services as opportunities for anticipating and mitigating operational risks and for accessing actionable information within a very short time span compared to comparable data sets from conventional sources.

6.8 Widespread accessibility to free quality satellite imagery

Free high resolution up-to-date satellite imagery is necessary for efficient UAV pre-flight operations like flight planning, flight range determination, or minimum elevation setting. These kinds of data are available across most of the African continent and represent an enabling environment for the technology to be deployed. In comparison, in Eastern Europe for example, it is sometimes challenging to access quality remote-sensed data.

6.9 Natural resources monitoring and surveillance

With the ever-increasing demand on Africa's natural resources, the ability to closely monitor and get accurate timely information is critical. Precision agriculture techniques have until now, only been accessible by large-scale Western farmers where economies of scale warranted the investment in what used to be expensive hardware and/or services. The reduction in cost, size and complexity of modern UAVs and associated sensors means that African farmers can leapfrog from more traditional methods of agriculture to ultra-modern precision agriculture (Mbonyinshuti, 2016).

6.10 Easy-to-deploy solutions for reaching poorly accessible areas

Rural areas in many African countries are difficult to access due to poor or non-existent road infrastructure. Areas that suffered, or are suffering from the impact of conflicts or natural disasters face even worse access constraints. Drone technology offers the opportunity for reaching such areas and providing a selected range of services like delivery of small quantities of goods (e.g. medical supplies) or to inspect and survey disaster-stricken infrastructure

7

Conclusion

Drones for precision agriculture may be perceived as an intensive high technology-driven approach, but there are aspects of precision agriculture that are already being used in Africa, including location-based information on soils and use of variable rate technology. UAS technology has the potential to help farmers maximise their resources and provide rich, timely and granular or detailed data. Harnessing precision agriculture with the use of drones in the context of large- to medium-scale farms, as well as cooperative endeavours, is likely to result in increased agricultural productivity and returns to investment and improved environmental sustainability.

In the context of smallholdings, UAS services are likely to be affordable to farmers who are part of large cooperatives growing the same crop on contiguous areas. This emerging technology has been successfully put into practice for farm mechanization in Rwanda under the CIP framework. Within this context farmers synchronize crop cultivation on lands that are consolidated and rearranged to form larger and more rational holdings. In line with the economies of scale, as UAS services become cheaper, the larger the targeted areas. Hence, the most likely UAS adopters will be large farmers' associations or cooperatives, contract farming enterprises, and medium and large-scale farms and agribusinesses.

Driven by increasing demand, drone technology is expanding at an exponential scale in the West and agriculture is one of the top economic sectors where they are being used. Africa should not lag behind. Therefore, through a consultative process, African Union Member States need to develop and enact national UAV regulatory frameworks, which ensure safety, encourage innovation and do not restrict the emergence of UAS agro-service providers or discourage private sector investment in the industry.

UAS used for surveying purposes can help address land administration issues especially for rural smallholders and informal land tenure situations. Clearer land rights will also result in better access to credit and financial security. In an urban setting UAS surveys can lead to the production of high-resolution imagery and maps. These can help city planners to improve infrastructure and address natural calamity hazards (e.g. floods).

The process of economic development is complex and nonlinear. This process is further complicated by the fact that many emerging technologies due to their productivity-enhancing nature, result in reducing the need for low-skilled labour. In Africa, where the vast majority of countries account for large numbers of unemployed youth and adults, such developments must go hand-in-hand with other social, economic and educational activities. Africa needs a skilled workforce able to manage the data infrastructure required to store, handle and exchange the data that is being created. Africa needs UAV pilots, data analysts, researchers, agronomists, city planners who are all skilled to a high degree to be able to utilize the data. Africa needs an environment that encourages investment in innovative, game-changing technologies. This can only be achieved when all stakeholders concerned come together to put in place a regulatory environment with effective governance structures.

8

Recommendations

With the current status of drone technology uptake and the opportunities it offers in crop scouting and monitoring, crop volume assessments, inventory, precision spraying, and crop damage assessment, Africa is set to increase its agricultural productivity in the next decade.

Key areas to be considered in upscaling the technology and realising its potential include capacity-building, enabling or supporting infrastructure, regulatory strengthening, research and development and stakeholder engagement. In this regard, the African Union High-Level Panel on Emerging Technologies recommends the following:

At the national level:

- Assess the opportunity cost of UAV technology including external factors and balance it against expected outcomes such as food security, improved health and the potential for drones to make agriculture attractive to the youth.
- Ensure that stakeholders are engaged in all aspects related to the development of UAV technology so that potential resistance is understood and dealt with systematically.
- Conduct public awareness and capacity building around UASs and their civil applications to clearly distinguish between civil and military uses. This approach will thereby improve public acceptance. Safety, security and privacy concerns need to be addressed as part of this process.
- Address cost and technical barriers to the adoption of the technology through either subsidies, licensed SMEs or cooperatives, and build a supportive framework for drone governance and regulation to facilitate adoption (including licensing and registration).
- Encourage and support public-private partnerships for UAV technology uptake.
- Ensure that appropriate national UAV regulations are put in place. Suitable regulations should strike a balance between competing public security concerns on one hand and the need to encourage innovation, economic development and youth entrepreneurship, on the other. In this context, encourage National Civil Aviation Authorities to establish enabling regulatory frameworks for UAV technology to be deployed and up-scaled to serve precision agriculture.
- Allocate financial resources for research and development (cost & benefits) and capacity building to form critical mass in all aspects of drone technology – licensed pilots, scientists, regulators and relevant stakeholders.
- In the context of smallholder farmers, support crop intensification through stimulating the planting of the same crops simultaneously in contiguous areas to form larger holdings which could reap the benefits of UAV technology for precision agriculture.

At the continental level:

- Develop continental regulatory framework for the use of UAVs in Africa, and harmonize policies across countries and regions (regional economic communities)
- Enhance South-South, triangular and regional collaborations, partnerships, networks and knowledge-exchanges to facilitate upscaling and use of drone technology.

9

Bibliography

Adewopo, J. (2017, August 31). *Regulations and realities in Nigeria's UAV airspace*. Retrieved from CTA Corporate: https://goo.gl/onfRQB

Afrotech. (2016, April 12). *Redline*. Retrieved March 7, 2017, from EPFL: https://afrotech.epfl.ch/page-115280-en.html

Ajewole, P., Elegbeleye, K., & Oladipo, I. (2016). *The Prospects of Precision Agriculture in Nigeria.* Department of Agricultural Engineering.

Atherton. (2016, March). *Spanish Drone will Drop Insects over Ethiopia to Fight Disease*. Retrieved from Popular Science: https://goo.gl/3N6Ul2

Avila-Robinson, A., & Miyazaki, K. (2011). Conceptualization and operationalization of emerging technologies: a complementing approach. *PICMET'11*, *Technology Management in the Energy Smart World (PICMET)*, pp. 1-12.

Belton, P. (2015, January 16). *Game of drones: As prices plummet drones are taking off.* Retrieved March 10, 2017, from BBC News: http://www.bbc.com/news/business-30820399

Blein, R., & Bwalya, M. (2013). *Agriculture in Africa: Transformation and outlook.* New Partnership for African Development (NEPAD).

Bramley, R. (2009). Lessons from nearly 20 years of Precision Agriculture research, development, and adoption as a guide to its appropriate application. *Crop and Pasture Science, 60*, 197-217.

Civil Aviation Authority (UK). (2017, July 14). *Small Unmanned Aircraft (SUA) operators holding a valid CAA permission.* Retrieved July 30, 2017, from https://publicapps.caa.co.uk/docs/33/20170714RptUAVcurrent.pdf

Clothier, R., Greer, D., & Greer, D. (2015). Risk, Perception and the Public Acceptance of Drones. *Risk Analysis*.

Cozzens, S., Gatchair, J., Kang, K., King, H., Lee, G., Ordóñez, A., & Porter, A. (2010). Emerging technologies: quantitative identification and measurement. *Technol. Anal. Strateg. Manag.*, pp. 361-376.

de Klerk, M., Droogers, P., Simons, G., & van Til, J. (2016). *Change in Water Productivity as a Result of ThirdEye Services in Mozambique. Report 157.* Wageningen: FutureWater.

DJI. (2016). *DJI GO App Now Includes GEO Geofencing System*. Retrieved July 21, 2017, from https://goo.gl/gDoF1x

Drone Powered Solutions. (2016). Clarity from above. PwC global report on the commercial applications of drone technology. Warsaw: PWC.

EADM. (2017). *EAC to Hold Regional Conference on Drone Operations Regulations.* East African Diaspora Market Watch. Retrieved from http://eadm.news/39-carousel/big/279-eac-to-hold-regional-conference-on-drone-operations-regulations

EASA. (2017). *Civil drones (Unmanned aircraft)*. Retrieved from European Aviation Safety Agency (EASA): https://www.easa.europa.eu/easa-and-you/civil-drones-rpas

EC. (2016, November 23). *Drones: Commissioner Bulc presents plans for the creation of a European drone services market*. Retrieved from Directorate General for Mobility and Transport: https://goo.gl/Dgd3EG

Efron, S. (2015). *The Use of Unmanned Aerial Systems for Agriculture in Africa: Can It Fly?* Santa Monica: RAND Corporation. Retrieved from https://www.rand.org/pubs/rgs_dissertations/RGSD359.html

Eichleay, Mercer, Murashani, & Evens. (2016). *Using Unmanned Aerial Vehicles for Development: Perspectives from Citizens and Government Officials in Tanzania.* FHI360.

Estes, C., Hinton, D., Robinson, D., & Lane, E. (2015). *Aerial Systems, Governance.* NASIO.

FAO/IAEA. (2016). *Drones for Good 2016: FAO/IAEA's ROMEO system for aerial release of sterile male mosquitoes*. Retrieved from Joined FAO/IAEA Programme: https://goo.gl/JFBASD

Forni, A. A., & Rob, v. (2017, 2 9). *Gartner Says Almost 3 Million Personal and Commercial Drones Will Be Shipped in 2017*. Retrieved from Gartner: http://www.gartner.com/newsroom/id/3602317

FSD. (2017). *Global Drone Regulations Database*. Retrieved April 8, 2017, from Drone Regulations Info: https://www.droneregulations.info

FSD. (n.d.). *Global Drone Regulations Database*. Retrieved April 8, 2017, from Drone Regulations Info: https://www.droneregulations.info

Garg, R. (2016, April). Insuring Indian farmers more effectively. *ICT Update*, p. 12.

Gassner, A., & Sinclair, F. (2013). *Precision Agriculture for Sustainability and Environmental Protection.* Routledge.

Gebbers , R., & Adamchuk, V. (2010). Precision agriculture and food security. *Science, 327*, 828-831.

Gilman, D. (2015). *Unmanned Aerial Vehicles in Humanitarian Response*. Policy Development and Studies Branch, United Nations Office for the Coordination of Humanitarian Affairs (OCHA).

Goddard, T., Lachapelle, G., Cannon, M., Penney, D., & McKenzie, R. (1995). The potential of GPS and GIS in precision agriculture. *Proc. Geomatique V: "La Route De L'Innovation".* Montreal, P.Q., Canada.

Godwin, R., Wood, G., Taylor, J., Knight, S., & Welsh, J. (2003). Precision farming of cereal crops: a review of a six year experiment to develop management guidelines. *Biosystems Engineering, 84*, 375-391.

Grand View Research. (2016). *Commercial Drone Market Analysis By Product (Fixed Wing, Rotary Blade, Nano, Hybrid), By Application (Agriculture, Energy, Government, Media & Entertainment) And Segment Forecasts To 2022.* Grand View Research.

Greenwood, S. (2016, April). Drones on the Horizon: new frontier in agricultural innovation. *ICT Update*, pp. 2-3.

Hardy, A., Makame, M., Cross, D., Majambere, S., & Msellem, M. (2017). Using low-cost drones to map malaria vector habitats. *Parasites & Vectors*.

Harris, K. (2015, September 16). *Proposals for Droneport project launched to save lives and build economies*. Retrieved March 02, 2017, from Foster + Partners: https://goo.gl/GrbmHC

Hendriks, J. (2011). *An analysis of precision agriculture in the South African summer grain producing areas.* North-West University, South Africa.

Hogan, S., Kelly, M., Stark, B., & Chen, Y. (2017). Unmanned aerial systems for agriculture and natural resources. *California Agriculture*, 5-14.

ICAO. (2017, March). *Safety.* Retrieved from ICAO: https://goo.gl/XlhMlN

Jeanneret, C. (2016, April). Making sense of drone regulations. *ICT Update*, pp. 22-23.

Jeanneret, C., & Rambaldi, G. (2016). *Drone governance: a scan of policies, laws and regulations governing the use of unmanned aerial vehicles (UAVs) in 79 countries.* Waheningen: CTA.

Kathiresan, A. (2011). *Strategies for Sustainable Crop Intensification in Rwanda. Shifting focus from producing enough to producing surplus.* KIgali: MINAGRI.

Leone, A., Wright, G., & Corves, C. (1995). The application of satellite remote sensing for soil studies in upland areas of Southern Italy. *Int. J. Remote Sensing, 16*, 1087-1105.

Look, A. (2013, December 20). *Civilian Drones Raise Hopes, Questions in Africa*. Retrieved from VOANews: https://goo.gl/9AaOEo

Makoye, K. (2016, September 8). *Tanzania turns to drones to bring peace in bitter fight for land.* Retrieved from Reuters: https://goo.gl/E2lQMw

Mbonyinshuti, J. d. (2016, December 8). *Drone to monitor crops in Northern Province*. Retrieved March 25, 2017, from The New Times: https://goo.gl/5d0fka

McGoogan, C. (2016, July 22). *Facebook's solar-powered internet drone takes maiden flight*. Retrieved March 11, 2017, from The Telegraph: https://goo.gl/QV9nji

Mulero-Pázmány , M., Stolper , R., van Essen, L., Negro, J., & Sassen , T. (2014). *Remotely Piloted Aircraft Systems as a Rhinoceros Anti-Poaching Tool in Africa.* PLoS ONE.

NCAA. (2017, June 22). *NCAA issues first RPAS/ Drones operator certificate to Oando* . Retrieved from Nigerian Civil Aviation Authority (NCAA): http://www.ncaa.gov.ng/ncaa-issues-first-rpas-drones-operator-certificate-to-oando/

Nkala, O. (2014, September 10). *Namibia deploys UAVs for anti-poaching operations*. Retrieved from DefenseWeb: http://www.defenceweb.co.za/index.php?option=com_content&view=article&id=36222:namibia-deploys-uavs-for-anti-poaching-operations&catid=35:Aerospace&Itemid=107

NUWER, R. (2017, March 13). *High Above, Drones Keep Watchful Eyes on Wildlife in Africa*. Retrieved from The New York Times: https://www.nytimes.com/2017/03/13/science/drones-africa-poachers-wildlife.html?hp&action=click&pgtype=Homepage&clickSource=wide-thumb&module=mini-moth&region=top-stories-below&WT.nav=top-stories-below&_r=2

Nwili, F. (2016, 06 10). *Amid Allegations Of IP Theft By Corporations, Local Kenyan Innovators React*. Retrieved from Intellectual Propeerty Watch: https://www.ip-watch.org/2016/06/10/amid-allegations-of-ip-theft-by-corporations-local-kenyan-innovators-react/

Orellana, J., Best, S., & Claret, M. (2006). Sistemas de Información Geográfica (SIG). *AGRICULTURA DE PRECISIÓN: Integrando conocimientos para una agricultura moderna y sustentable*.

PrecisionHawk. (2016, May 26). *Munich Re Selects PrecisionHawk to Improve Post-Catastrophe Assessment Using Drone Technology*. Retrieved from PR Newswire: https://goo.gl/sGVsnl

PricewaterhouseCoopers. (2016). *Global Market for Commercial Applications of Drone Technology Valued at over $127 bn*. Retrieved from PCW: https://goo.gl/Gaz09L

Ramani Huria. (2016). *Community Mapping For Flood Resilience and Development*. Retrieved from http://ramanihuria.org/

Rambaldi, G., & Guerin, D. (2017). Regulations and Good Practice in the use of UAVs. *E-Agriculture in Action*.

Robert, P. (2002). Precision agriculture: a challenge for crop nutrition management. *Plant and Soil, 247*, pp. 143-149.

Rosen, W. J. (2017). Zipline's Ambitious Medical Drone Delivery in Africa.

Rwanda Biomedical Center. (2016, October 14). Retrieved from Rwanda Biomedical Cente: http://www.rbc.gov.rw/IMG/pdf/press_release_medical_drones_deliveries.pdf

Rwanda Biomedical Center. (2016, October 14). Retrieved from Rwanda Biomedical Cente: http://www.rbc.gov.rw/IMG/pdf/press_release_medical_drones_deliveries.pdf

Soesilo, D. (2015). *Obtaining High-Resolution Imagery to Map and Model Flood Risks in Dar es Salaam.* FSD.

Soesilo, D., & Bergtora Sandvik, K. (2016). *Drones in Humanitarian Action – A survey on perceptions and applications.* Geneva: SFD.

Soesilo, D., Meier, P., Lessard-Fontaine, A., Du Plessis, J., Stuhlberger, C., & Fabbroni, V. (2016). *Drones in Humanitarian Action.* Retrieved from Drones for Humanitarian and Environmental Applications: https://goo.gl/aDtz4p

Soesilo, Meier, Lessard-Fontaine, Plessis, D., & Stuhlberger. (2016). *Drones for Humanitarian and Environmental Applications: A guide to the use of airborne systems in humanitarian crises.* Geneva: FSD.

Sweeney, S. (2015). *View from Above: Using Drones to Help Support Conservation in Tchimpounga* . Retrieved from Jane Goodall's Good for All News: http://news.janegoodall.org/2015/11/16/view-from-above-using-drones-to-help-support-conservation-in-tchimpounga/

Talebpour, B., Türker, U., & Yegül, U. (2015). he Role of Precision Agriculture in Promotion of Food Security. *International Journal of Agricultural and Food Research, 4*, 1-23.

Thompson, W., & Robert, P. (1994). Valuation of mapping strategies for variable rate applications. *Proc. Site-Specific Management for Agricultural Systems* (pp. 303-323). Minneapolis: ASA-CSSA-SSSA.

UAV Insider. (2013, August 15). Retrieved March 20, 2017, from UAV Insider | Unmanned Aerial Vehicle Drone News for Civil Industry: https://goo.gl/8VoVqS

UAViators. (2017, March). *Humanitarian UAV Code of Conduct & Guidelines.* Retrieved from https://goo.gl/ubekSR

UNDP Equator Initiative. (2015). *South Central People's Development Association, 2015 Winner of the Equator Prize.* Retrieved from https://goo.gl/TyYvXy

UNICEF. (2016, July 27). *From killing machines to agents of hope: the future of drones in Africa*. Retrieved from UNICEF stories: https://goo.gl/r90yMR

UNICEF. (2016, December 15). *The Government of Malawi and UNICEF announce first humanitarian drone testing corridor in Africa*. Retrieved March 09, 2017, from UNICEF Press Centre: https://www.unicef.org/media/media_94184.html

Vermeulen, C., Lejeune, P., Lisein, J., Sawadogo, P., & Bouché, P. (2013). Unmanned Aerial Survey of Elephants.

Volkmann, W. (2017). *Small Unmanned Aerial System mapping versus Conventional methods: Case studies on farmland surveying.* Wageningen: CTA.

Warner, B. (2013, march 6). *What Africa Can Teach Us About the Future of Banking.* Retrieved March 3, 2017, from Bloomberg: chttps://goo.gl/OiU1TP

Wijnberg. (2017, September 7). *Are South African regulations stifling the drone-based agri-service industry, a potential game-changer for agriculture?* Retrieved from CTA Corporate: https://goo.gl/iiaYp3

Wijnberg, L. (2017, July 22). CEO, 3DroneMapping.

World Food Programme. (2017, February 3). *WFP And Belgium Start Efforts To Deploy Drones In Humanitarian Emergencies*. Retrieved from World Food Programme, News: https://goo.gl/9bTmJj

Yao, H., & Wu, Y. (2011). A Research about the Application of Information Technology in the Precision Agriculture: Taking the Operating System of Shanghai Agriculture Economy as an Example. Springer.

Yingqun, A. W. (2016, 11 18). *Drones Take Off*. Retrieved from China Daily Africa: http://africa.chinadaily.com.cn/weekly/2016-11/18/content_27415901.htm

Zanzibar Commision for Lands. (2017). Retrieved March 25, 2017, from Zanzibar Mapping Initiative: http://www.zanzibarmapping.com/

Zarco-Tejada. (2014). *Precision Agriculture: An Opportunity for EU Farmers-Potential Support with the CAP 2014-2020.* Joint Research Centre (JRC) of the European Commission.

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