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The Use of Unmanned Aerial Systems for Agriculture in Africa
Can It Fly?

Shira Efron
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This document was submitted as a dissertation in August 2015 in partial fulfillment of the requirements of the doctoral degree in public policy analysis at the Pardee RAND Graduate School. The faculty committee that supervised and approved the dissertation consisted of Jeanne Ringel (Chair), Dave Baiocchi, and Brien Alkire.
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Executive Summary

I. Research Objectives

Food insecurity in Africa is an imminent threat. Currently, 240 million people in Sub-Saharan Africa—one person in every four—lack adequate food.\(^1\) Higher temperatures and lower rainfall in parts of Africa, combined with a doubling of the population, are projected to increase food insecurity in the continent by 43 percent by 2030.\(^2\) Despite accelerated globalization, local agricultural production in Africa remains critical to both food security and economic development among the rural poor, and increasing agricultural productivity remains an enormous challenge. Research suggests that at least a doubling of agricultural yields is required over the coming decades in economies where, as is the case in Sub-Saharan Africa, a majority of the population depends on smallholder farming. Moreover, the agricultural expansion required to feed a growing population is expected to have detrimental environmental impacts.\(^3\) Already, farming input use and irresponsible agricultural practices are harmful, and trade off short-term agricultural gains against reduced potential for food production. As a result, food security is threatened, over the longer term.

Policymakers are looking for new technologies to boost agricultural yields in Africa in more efficient and environmentally sustainable ways. Unmanned aerial systems (UAS), commonly known for their military uses, offer promise. In this interdisciplinary study, I investigate if and how UAS technology might improve agricultural output in Africa. Further, I identify drivers and barriers to agricultural UAS adoption, assess which countries in Africa are most and least likely to adopt the technology, and suggest steps that policy-makers can take to overcome barriers and promote UAS agricultural use.

II. Research Questions and Approach

The study addressed three broad research questions.

1. Can UASs add value to agriculture in Africa?
2. What non-technical factors are likely to influence UAS adoption in African agriculture?
3. Which countries in Africa are most likely to successfully adopt agricultural UAS technology?

I used a mixed-method approach to answer these research questions, following a five-phase research plan (Figure ES.1).
In order to meet the research objectives, I first conducted comprehensive literature reviews and consulted subject matter experts (SMEs) with the aim of mapping out the agricultural UAS landscape and identifying agricultural challenges in Africa. My findings in this initial step guided the selection of two prominent agricultural insect/pest problems that could potentially be mitigated through the use of UAS technology: the Tsetse Fly and the Red-Billed Quelea. Both of these pests are endemic to Africa and are associated with tremendous agricultural and economic losses in the continent. After assessing the technical feasibility of using UAS to mitigate pest damage (e.g.), I conducted a field study in Kenya, in order to add context to the theoretical analysis and gain the perspectives of stakeholders in Africa who are likely to be involved in agricultural UAS adoption, should such take place.

Subsequently, I turned toward a more strategic view, seeking to assess the overall feasibility of agricultural UAS adoption across Africa. I developed a framework that considers all important aspects of this issue: national wealth, innovation capacity, technical literacy of the workforce, governance and institutions, and public acceptance. I then used this framework to detect variation among 36 countries in Africa in the likelihood that they successfully adopt agricultural UAS technology in the near future.

III. Findings

_UAS Meet the Requirements for Managing One of Africa’s Most Harmful Agricultural Pests—the Tsetse Fly_

Tsetse flies are vectors for the parasite Glossina palpalis gambiensis, which causes African animal trypanosomosis (AAT), one of the most devastating livestock diseases in sub-Saharan Africa. Tsetse flies are estimated to transmit the often-lethal parasite to some three million animals\(^iv\) in 37 countries across the continent.
the continent each year. Costs associated with the Tsetse fly in terms of farmers’ livelihoods and increased food insecurity total more than $4.5 billion per annum.∞

One of the most effective and environmentally sustainable methods for eradicating Tsetse fly populations is the Sterile Insect Technique (SIT), in which masses of sterilized male flies are systematically released into infested areas, where they mate with wild females that then do not produce offspring, leading to the eventual elimination of Tsetse populations.√

Using a systems engineering and vignette analysis approach, I found that UAS offer clear advantages over the manned aircraft currently used in SIT programs, including lower fixed and operational costs, reduced environmental burden, and enhanced safety. Considering the payload weight requirement of the sterilized fly release machine and the flies (140 lb.) and line of sight (LOS) communications range limitations, the UAS classes found most compatible for this mission are either vertical take-off and landing (VTOL) or medium altitude, long endurance (MALE).

**UAS May Also Be Effective in Managing the Red-Billed Quelea Bird**

The Quelea is the most abundant wild bird species in the world,√ with an adult breeding population estimated at 1.5–5 billion pairs,√√ and a native range that extends over some six million square miles in Africa. The birds are a significant menace to subsistence farmers, causing over $80 million per annum√√ in economic losses and directly exacerbating food insecurity, and certainly a hazard to commercial farmers. Traditionally, two strategies are used in Quelea-control: (1) scaring them away using projectiles or noises and (2) lethal methods like dynamite or pesticides.

My analysis found that UAS can potentially support both strategies. Interviews with SMEs in the areas of Quelea-control and UAS indicated that this technology can supplant manned aircraft in chemical spraying of flocks, or help survey roosts and breeding colonies in preparation for lethal control methods. In addition, a UAS airframe designed to look like a Quelea predator and emitting both predator and Quelea-specific distress sounds can potentially replace human labor to deter birds from farmland.

Looking beyond these two specific examples, my research identified several non-technical factors that **policy-makers should consider when evaluating initiatives to adopt UAS technology (Table ES.1).** These findings are based on the field study that I conducted in Kenya that surveyed and interviewed multiple stakeholders (159 smallholder farmers, 14 NGO staff members and five Government officials.) Stakeholders helped identify potential drivers and barriers of using UAS to improve agricultural outcomes in Africa.
Table ES.1. Drivers and Barriers That Are Likely to Affect Adoption of Agricultural UAS across Africa

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Barriers</th>
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<tbody>
<tr>
<td>Severity of the problem</td>
<td>Imperfect mission fit</td>
</tr>
<tr>
<td>Lack of effective, acceptable solutions</td>
<td>Cost</td>
</tr>
<tr>
<td>Interest in innovative, mechanized methods</td>
<td>Technical feasibility (undeveloped infrastructure, technical illiteracy)</td>
</tr>
<tr>
<td>Multipurpose nature of solution (UAS for pest management and remote sensing)</td>
<td>Security issues</td>
</tr>
<tr>
<td>Support from strong stakeholders</td>
<td>Privacy concerns</td>
</tr>
<tr>
<td>Ability of UAS to draw youth into agriculture</td>
<td>Legal restrictions (and politics)</td>
</tr>
</tbody>
</table>

Recognizing that these drivers and barriers exist, I created a framework that decisionmakers can use to assess the feasibility of adopting agricultural UAS across Africa. The framework assesses likelihood along five separate dimensions: innovative capacity, technical literacy, affordability, institutional capacity, and cultural acceptance.

The framework offers a useful lens through which policy-makers can examine the feasibility of implementing UAS-based agricultural programs throughout the continent. Its benefits in particular include:

- **It is comprehensive and modular.** The comprehensiveness of the framework, combined with its modularity and versatility, allows for different levels of analyses, from assessment along a single dimension; a partial analysis, integrating only a few of the four dimensions; or a holistic one, incorporating all dimensions. The decision about which dimensions should be used to assess the likelihood of adoption is context-dependent, and depends on the objectives of the framework’s users.

- **It is a useful tool for policymakers.** Policymakers interested in examining the feasibility of adopting UAS for agriculture in Africa can use this tool for a ‘quick and dirty’ analysis on which country in Africa is currently most ripe for the technology. Alternatively, this tool can be used for examining how a specific country is influenced by multiple dimensions. The latter type of analysis can help identify the presence and scale of barriers, and accordingly prioritize the areas in which they should focus efforts to improve the likelihood of successful UAS adoption. For example, Burundi is ranked low along two dimensions—35th in affordability and 33rd in institutional feasibility. It is ranked around the middle in technical feasibility (19th), and in the top third of cultural feasibility (12th). Thus, policymakers interested in promoting the technology in Burundi should focus efforts on the dimensions that may hinder adoption, and not devote valuable resources to campaigns on dimensions where adoption seems more likely—for example, in the case of Burundi, on cultural acceptance.

- **It is quantitative, simple, and promotes transparency.** To ensure the transparency and simplicity of the framework, I assigned quantitative metrics to each dimension that allowed for ranking of the 36 countries, from the country most likely to successfully adopt the technology to the least likely to do so (Table ES.2). These metrics include commonly-used indicators (e.g., GDP
per capita, tertiary education) and innovative ones (modified Global Innovation Index, Ibrahim Index of African Governance, Hofstede’s Dimensions of National Culture).

- **It is agile and can be used for examining other technologies.** Different from existing technology adoption frameworks, this tool also considers the cultural acceptance dimension, which is particularly relevant for controversial technologies such as UAS. Inclusion of cultural acceptance makes this framework useful for analyzing the feasibility of adopting other stigmatized technologies, either in agriculture, e.g., genetically modified organisms (GMOs), or other dual-use technologies, e.g., nuclear energy.

Based on this framework, I identified the top countries that are most ripe to successfully adopt agricultural UAS: South Africa, Mauritius, Seychelles, Botswana, Namibia and Cabo Verde. The six countries least likely to be able to do so are: Togo, Guinea, Niger, Mozambique, Mali and Malawi. Using stoplight chart colors, I designed maps in ArcGIS that offer a visual representation and a first order assessment of this inter-country variation, along both individual dimensions and combined (Figure ES.2).
Table ES.2. Feasibility Rankings along Framework’s Dimensions, and Combined

<table>
<thead>
<tr>
<th>Affordability</th>
<th>Technical Feasibility</th>
<th>Institutional Feasibility</th>
<th>Cultural Feasibility</th>
<th>Combined Feasibility</th>
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<td>Country</td>
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<td>1</td>
<td>Seychelles</td>
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<td>Zambia</td>
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Figure ES.2: Variation in Likelihood of Successful UAS Adoption, Along All Dimensions
IV. Policy Recommendations

Drawing on the study’s findings, I developed a set of key recommendations that could feasibly be implemented with policy changes:

1. **Use a comprehensive multistep process to analyze the compatibility of UAS for the task and the feasibility of adoption.** Despite recent unprecedented interest in agricultural UAS, adopting this technology in Africa is not a simple issue. Thus, it is vital to assess whether this technology indeed offers a better solution than alternative methods, and how feasible adoption is in the local context. Such an analysis can take different forms, including systems-engineering methodology, surveys, and interviews with relevant stakeholders.

2. **Fully assess the costs and benefits of employing UAS, including non-pecuniary dimensions.** For example, such an analysis should consider on one hand the costs of unemployment resulting from UAS in agriculture as well as the externalities imposed by UAS use in one area on another; on the other hand, the analysis should include the opportunity costs associated with the status quo, the effects on food security and health outcomes, and the potential ability of UAS to draw more youth into employment in the agricultural sector.

3. **Reduce resistance to UAS adoption among those who are at risk of losing their jobs.** While UAS can create new types of jobs and bring economic benefits, it can also, like any other technology, replace human labor. Thus, if the analyses proposed in Recommendations 1 and 2 find that UAS offer a feasible solution to an agricultural problem, it is essential to address potential resistance before implementing the UAS programs. A stakeholder analysis followed by stakeholder engagement throughout the implementation process can further this objective.

4. **Improve public acceptance of agricultural UAS by disassociating it from military “drones.”** Another type of resistance to dual use civilian-military innovations is fueled by technology stigmatization. This study found that the association of UAS with military “drones” has stigmatized the technology. Thus, successful adoption of UAS for agricultural purposes will require addressing the security, safety, and privacy concerns surrounding the technology and distinguish agricultural UAS from their military counterparts both in design (e.g., paint them in bright colors) and the way the technology is introduced to the public.

5. **Consider different implementation models to lower cost and technical barriers.** To overcome the barriers that were cited during the field study in Kenya, various implementation models should be considered, depending for instance on the type of agricultural mission, cost of the potential UAS solution, geographical range, countries involved and their national wealth. Under different implementation designs, smallholder farmers can either be end-users (if the technology is subsidized) or customers (if a national government, NGO, an intergovernmental organization, or a private entity provides services employing UAS based on need).

6. **Capitalize on the potential of UAS to draw youth into agriculture.** One of the most important drivers identified in the analysis of UAS for Quelea control is the projected power of this technology to draw youth into agriculture. Hence, informational and media campaigns on agricultural UAS should not only emphasize the potential positive effect UAS can have on agriculture and food security, and the unique solution this technology provides, but should also highlight that its UAS may help reverse the alarming trend of an aging farmer population.

7. **Future research $ should be used to deepen understanding of issues explored in this study, primarily in the following areas:**
- Technical challenges of civilian UAS (e.g., sense-and-avoid; data link resilience; LOS communications range limitations)
- Additional agricultural UAS tasks in Africa (e.g., monitoring soil moisture; providing accurate and timely information for precision farming; crop dusting).
- Improved measures of non-technical factors affecting adoption feasibility (e.g., better cultural acceptance metric, assessment of legal aviation regimes.)

V. Conclusion

UAS represent an exciting innovation that shows great potential for improving agricultural outcomes in Africa. However, because this technology is so advanced, currently there is a gap between the technology and the policy environment in which it is to be adopted. In the near future, policymakers should examine how UAS can help mitigate agricultural problems of prime importance, and they should design policies to support the implementation of this technology for agriculture and human development in African countries.
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Abbreviations

AAT African animal trypanosomosis
AGL above ground level
ARVs antiretroviral drugs
ATC air traffic control
AUVSI Association for Unmanned Vehicle Systems International
AW-IPM area-wide integrated pest management
B/W black/white
BLOS beyond line-of-sight
C2 command and control
C3 command, control, and communications
CBFM community-based forest monitoring
CDL common data link
COTS commercial off-the-shelf
CPIA Country Policy and Institutional Assessment
CRS Christian Relief Services
DGPS Differential Global Positioning System
DSV Directorate of Veterinary Services
ELINT electronic intelligence
ERAST Environmental Research Aircraft and Sensor Technology
FAA Federal Aviation Administration
FAO Food and Agriculture Organization of the United Nations
FAPAR Fraction of Absorbed Photosynthetically Active Radiation
FIAN Food First Information and Action Network
FDI foreign direct investment
GAO Government Accountability Office
GII Global Innovation Index
GIS Geographic Information System
GloPac Global Hawk Pacific Mission
GMOs genetically modified organisms
<table>
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<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>GNI</td>
<td>Gross National Income</td>
</tr>
<tr>
<td>GPH</td>
<td>gallons per hour</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>HALE</td>
<td>High Altitude, Long Endurance</td>
</tr>
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<td>HAT</td>
<td>Human African Trypanosomiasis</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Energy Agency</td>
</tr>
<tr>
<td>ICT</td>
<td>information and communication technologies</td>
</tr>
<tr>
<td>IDV</td>
<td>Individualism versus Collectivism</td>
</tr>
<tr>
<td>IGO</td>
<td>international organization / inter-governmental organization</td>
</tr>
<tr>
<td>IIAG</td>
<td>Ibrahim Index of African Governance</td>
</tr>
<tr>
<td>IMF</td>
<td>International Monetary Fund</td>
</tr>
<tr>
<td>INCOSE</td>
<td>International Council on Systems Engineering</td>
</tr>
<tr>
<td>IR</td>
<td>international relations</td>
</tr>
<tr>
<td>ISR</td>
<td>intelligence, surveillance and reconnaissance</td>
</tr>
<tr>
<td>ISRA</td>
<td>Senegal Institute for Agricultural Research</td>
</tr>
<tr>
<td>KES</td>
<td>Kenyan Shilling</td>
</tr>
<tr>
<td>KWS</td>
<td>Kenyan Wildlife Service</td>
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<tr>
<td>LAI</td>
<td>leaf area index</td>
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<tr>
<td>LALE</td>
<td>Low Altitude, Long Endurance</td>
</tr>
<tr>
<td>LAMs</td>
<td>loitering attack munitions</td>
</tr>
<tr>
<td>LARS</td>
<td>Low altitude remote sensing</td>
</tr>
<tr>
<td>LASE</td>
<td>Low Altitude, Short-Endurance</td>
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<tr>
<td>LOS</td>
<td>line-of-sight</td>
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<tr>
<td>LST</td>
<td>land surface temperature</td>
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<tr>
<td>LTO</td>
<td>Long Term Orientation</td>
</tr>
<tr>
<td>LWIR</td>
<td>long-wave infrared</td>
</tr>
<tr>
<td>MALE</td>
<td>Medium Altitude, Long Endurance</td>
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<tr>
<td>MAS</td>
<td>Masculinity versus Femininity</td>
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<td>MAV</td>
<td>Micro or Miniature unmanned aerial vehicle</td>
</tr>
<tr>
<td>MPH</td>
<td>miles per hour</td>
</tr>
<tr>
<td>MSRM2</td>
<td>Mubarqui Smart Release Machine</td>
</tr>
<tr>
<td>MTCR</td>
<td>Missile Technology Control Regime</td>
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<tr>
<td>MWIR</td>
<td>middle-wave infrared</td>
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<table>
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<th>Full Form</th>
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<td>NAAA</td>
<td>National Agricultural Aviation Association</td>
</tr>
<tr>
<td>NAV</td>
<td>nano unmanned air vehicles</td>
</tr>
<tr>
<td>NDVI</td>
<td>Normalized Difference Vegetation Index</td>
</tr>
<tr>
<td>NDWI</td>
<td>Normalized Difference Water Index</td>
</tr>
<tr>
<td>NGO</td>
<td>non-governmental organization</td>
</tr>
<tr>
<td>OAF</td>
<td>One Acre Fund</td>
</tr>
<tr>
<td>PA</td>
<td>precision agriculture</td>
</tr>
<tr>
<td>PAR</td>
<td>photosynthetically active solar radiation</td>
</tr>
<tr>
<td>PATTEC</td>
<td>Pan African Tsetse and Trypanosomosis Eradication Campaign</td>
</tr>
<tr>
<td>PDI</td>
<td>Power Distance (indicator)</td>
</tr>
<tr>
<td>PPP</td>
<td>purchasing power parity</td>
</tr>
<tr>
<td>PUI</td>
<td>Peaceful Uses Initiative</td>
</tr>
<tr>
<td>RADAR</td>
<td>Radio detection And ranging</td>
</tr>
<tr>
<td>RC</td>
<td>radio-controlled</td>
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<tr>
<td>RCASS</td>
<td>Remote-Controlled Aerial Spraying System</td>
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<tr>
<td>RF</td>
<td>radio frequency</td>
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<tr>
<td>RPA</td>
<td>remotely piloted aircraft</td>
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<td>RPV</td>
<td>remotely-piloted vehicle</td>
</tr>
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<td>RS</td>
<td>remote sensing</td>
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<tr>
<td>RVI</td>
<td>Ratio Vegetation Index</td>
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<tr>
<td>SAR</td>
<td>synthetic aperture radar</td>
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<tr>
<td>SAT</td>
<td>aerosol spraying technique</td>
</tr>
<tr>
<td>SATCOM</td>
<td>satellite communications</td>
</tr>
<tr>
<td>SAVI</td>
<td>Soil Adjusted Vegetation Index</td>
</tr>
<tr>
<td>SIT</td>
<td>sterile insect technique</td>
</tr>
<tr>
<td>SME</td>
<td>subject matter expert</td>
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<tr>
<td>SOPs</td>
<td>standard operating procedures</td>
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<tr>
<td>sUAS</td>
<td>small unmanned aerial systems</td>
</tr>
<tr>
<td>TAM</td>
<td>Technology Acceptance Model</td>
</tr>
<tr>
<td>TCAS</td>
<td>Traffic Collision Avoidance System</td>
</tr>
<tr>
<td>TIR</td>
<td>thermal infrared</td>
</tr>
<tr>
<td>TNDVI</td>
<td>Transformed Normalized Difference Vegetation Index</td>
</tr>
<tr>
<td>TVI</td>
<td>Triangular Vegetation Index</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
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<td>-----------</td>
</tr>
<tr>
<td>UA</td>
<td>unmanned aircraft</td>
</tr>
<tr>
<td>UAI</td>
<td>Uncertainty Avoidance (indicator)</td>
</tr>
<tr>
<td>UAS</td>
<td>unmanned aerial systems</td>
</tr>
<tr>
<td>UAV</td>
<td>unmanned aerial vehicle</td>
</tr>
<tr>
<td>UCAV</td>
<td>unmanned combat air vehicles</td>
</tr>
<tr>
<td>UNDP</td>
<td>UN Development Program</td>
</tr>
<tr>
<td>USAF</td>
<td>United States Air Force</td>
</tr>
<tr>
<td>USDA</td>
<td>United States Department of Agriculture</td>
</tr>
<tr>
<td>VTOL</td>
<td>vertical take-off and landing</td>
</tr>
<tr>
<td>WFP</td>
<td>World Food Program</td>
</tr>
<tr>
<td>WGI</td>
<td>World Governance Indicators (of the World Bank’s)</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
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Chapter 1. Introduction

1.1 Background

Food security is defined as a situation in which all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active healthy life.\textsuperscript{xi} This definition includes elements of food availability, accessibility, and quality. Availability refers to the supply of food, which can be domestically produced, imported, or received as aid. Food access addresses the demand for food and is influenced by economic factors, physical infrastructure, and consumer preferences. Finally, for households and individuals to be food secure, accessible food must be adequate not only in quantity but also in quality.

Despite international commitment to reduce hunger,\textsuperscript{xii} and notwithstanding technical advances in food supply chains, food insecurity remains an imminent threat. The vulnerability of the global food system is driven by the mounting demand for food on one hand, and dwindling supply of food sources on the other. Population growth, changing diets, urbanization, erosion of land and water resources, and climate change all play a role.\textsuperscript{xiii} The future outlook does not look promising either. According to the United Nations’ Intergovernmental Panel on Climate Change, the world’s food supply is at considerable risk.\textsuperscript{xiv}

Worldwide, over 900 million people—one in eight—are undernourished. Even more alarming, over 100 million children under the age of five are underweight, and childhood malnutrition is a cause of death for more than five million children every year.\textsuperscript{xv} Most people affected by food insecurity live in developing countries. Nowhere is this problem more severe than in Africa. Sub-Saharan Africa is the largest concentrated block of hungry people in the world.\textsuperscript{xvi} Nearly 240 million people in sub-Saharan Africa—one person in every four—lack adequate food. Since 2006, record food prices and drought have been pushing more people into poverty and hunger.\textsuperscript{xvii} Today, 30 million children in sub-Saharan Africa—one in five—are underweight—5.5 million more than 20 years ago.\textsuperscript{xviii}

Food production in Africa has not kept up with population growth. While Africa experienced considerably faster population growth than any other major geographical area for most of the 1950–2000 period,\textsuperscript{xix} per capita food production in the continent declined by almost 20 percent between 1970 and 2000.\textsuperscript{xv} Moreover, as a result of rapid population growth, landholdings in Africa have consistently shrunk in size; currently 80 percent of the continent’s farms occupy less than two hectares. Ironically, smallholder farmers, the producers of over 90 percent of the Africa’s food supply, make up more than half of the food insecure population of the continent.\textsuperscript{xvi} Considering the sizeable population growth projected for Africa (from 796 million in 2005 to 1.8 billion by 2050\textsuperscript{xvii}), and given that the countries with the fastest-growing populations will be mainly in the sub-Saharan Africa, the future bodes ill for food
security in the continent unless decision-makers adopt policies that can narrow the gap between supply and demand for food.

1.2 Scope and Research Objectives

Africa faces daunting challenges in each of the determinants of food security (availability, accessibility and quality). However, this study focuses solely on food availability, the contribution of agriculture to food supply, and the potential contribution of technology to farming. In Africa, as in most of the developing world, food availability depends upon local food production; thus local agriculture is critical to promoting food security. Relatively to countries in Asia, crop output in Africa has remained stagnant in the last two decades. Between 1990 and 2006, the area under cultivation increased by more than 10 percent annually while cereal yields over the same period were largely unchanged. The average yields of grain crops in sub-Saharan Africa have stayed below 1 t/ha (ton/hectare) since the 1960s, compared with average cereal yields of 2.5 t/ha in South Asia and 4.5 t/ha in East Asia.xxiv

Erratic weather conditions in some areas and anticipated future effects of climate change make the prospect of higher crop yields in Africa uncertain.xxiv Current projections estimate that higher temperatures and lower rainfall in parts of Africa, combined with a doubling of the population, will increase food insecurity by 43 percent and will require a 60-percent increase in food aid expenditures over the next two decades.xxvi These figures are significant because the need for food aid is an indicator of many related problems, including child malnutrition and a decline in health, productivity and economic growth.xxvii The interaction between drought and declining agricultural capacity may be socially explosive, politically dangerous, and costly, with annual aid from industrialized countries totals projected to increase by 83 percent by 2030.xxviii

Moreover, research suggests that the agricultural expansion required to feed a growing population will have detrimental environmental impacts.xxx Already, fertilizer application, indiscriminate pesticide use, inattentive water schemes, and other irresponsible agricultural practices are harmful and trade off short-term agricultural gains at the expense of food insecurity for Africa’s population over the longer term.

Under such circumstances, policymakers are looking for new technologies to boost agricultural yields in more efficient and environmentally sustainable ways—for example, promotion of Evergreen Agriculture,xxx genetically modified organisms (GMOs),xxxi genetic research in the area of plant virus epidemiology,xxxii and precision farming.xxxiii

Surprisingly, unmanned aerial systems (UAS), commonly known for their military uses, offer promising developments in the field of agriculture. This technology is being touted as a suitable platform for data collection on health conditions of agricultural plots and individual crops. This information could in turn help target control and production materials to where they are most needed in an accurate and timely
manner. In addition, as this study will show, UAS may potentially deliver effective, and environmental-friendly, pest control measures.

Notwithstanding growing research on UAS, the literature review conducted for this study revealed important gaps in knowledge and understanding of potential agricultural applications of this technology. Most current literature focuses on remote sensing (RS; the acquisition of information about an object or phenomenon without making physical contact) and only to a lesser extent on delivery/aerial application missions. Moreover, only scant research in this field focuses on Africa, the continent that can benefit most from improved agricultural production. Finally, existing research typically focuses only on technical aspects of agricultural UAS technology even though evidence suggests that they constitute only a small part of the potential obstacles to their adoption. Rather, multiple factors, and the complex relationship between them, determine whether and how new technology applications will be adopted.

To begin to fill gaps in existing research, this interdisciplinary study investigates if and how UAS technology might improve agricultural output in Africa, identifies drivers and barriers to adoption, assesses which countries are most and least likely to adopt the technology, and suggests steps that policy-makers can take to overcome barriers and promote the use of UAS in agricultural missions.

1.3 Literature Review

Since 2008, an increasing number of articles published in peer-reviewed journals have focused on agricultural applications of UAS. Academic literature in this area can be divided into two broad categories: pilot studies examining narrow UAS missions, and extensive literature reviews.

The vast majority of pilot studies focus on very specific application, tested on a specific crop in a specific region, employing a specific platform and equipment. For example, Felderhof et al. provide a preliminary assessment of UAS technology for precision agriculture focusing on the macadamia industry in Australia. The most common analyses in this context explore how RS payload mounted on UAS can help detect crop and soil conditions, including spatial and temporal patterns of soil properties, uses of these technologies in precision agriculture; weed mapping and monitoring crop pests. Other studies mention the use of UAS for crop dusting and application of fertilizer on farmland. Only a few papers consider potential use of agricultural UAS for non-RS, non-crop dusting missions such as pest management.

Broader literature reviews of agricultural uses of UAS are a recent development. Most of the reviews consider specific types of missions and survey the literature for studies in this field across the globe. For example, Zhang and Kovacs review the application of low altitude remote sensing (LARS) systems mounted on UAS platforms as a way to promote precision agriculture (PA). Huang et al. present an overview of research involving the development of UAS technology for agricultural production management. These general studies have established that UAS are advantageous in comparison to satellites and manned aircraft for many applications, especially when it comes to small agricultural plots.
Some of the studies discuss shortcomings of the technology, such as platform and camera restrictions, and UAS data processing issues, and discuss challenges to its adoption, including considerations of reliability, design and cost.

However, these studies focus on agricultural UAS applications in industrialized countries, primarily the United States, Australia, Japan, and Israel. None of the papers reviewed considers how the unique characteristics of developing nations in general and Africa in particular may affect adoption of this technology. More generally, literature in this area lacks in-depth analysis of how non-technical barriers and drivers may affect implementation of agricultural UAS technology.

This dissertation adds to the literature on agricultural UAS applications in multiple ways. First, it focuses on how UAS can help increase food production, and alleviate hunger in Africa, the continent most affected by food insecurity. Moreover, it proposes innovative aerial delivery tasks for UAS in response to two of Africa’s most pressing agricultural challenges—the Tsetse fly and the Red-Billed Quelea bird. Finally, it looks beyond the technical aspects of UAS missions, and assesses the likelihood that this technology will be adopted across different countries in Africa.

1.4 Research Questions and Overview of Approach

The study addresses three basic research questions:

- **Question 1:** Can UASs add value to agriculture in Africa?
  - What advanced applications of UAS improve agriculture?
  - To which major African agricultural challenges can delivery missions carried out by UAS provide plausible solutions, and to what extent may these proposed UAS methods offer an improvement over currently-used technologies?

- **Question 2:** How non-technical factors are likely to influence UAS adoption in African agriculture?
  - What key drivers/barriers are likely to promote/hinder adoption of UAS for agriculture in Africa?
  - How can these drivers and barriers be modeled to assess the feasibility of adopting UAS technology for agriculture in Africa?

- **Question 3:** Which countries in Africa are most likely to successfully adopt agricultural UAS technology?
  - How can inter-country variation in the likelihood to successfully adopt agricultural UAS inform policymaking in this area?

The study used a mixed-method approach to answer these questions, including: comprehensive literature reviews; in-depth interviews with various types of subject matter experts (SMEs); systems engineering; a survey among smallholder farmers in Kenya; semi-structured interviews with key
informants and stakeholders along the grain production value chain in Kenya; and novel technology adoption analysis. Table 1.1 maps methodologies to research questions.

Table 1.1: Methodology by research question

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Literature Review</th>
<th>SME Interviews</th>
<th>Systems Engineering</th>
<th>Farmer Survey</th>
<th>Stakeholder Interviews</th>
<th>Adoption Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 1</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question 2</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question 3</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The general research plan was carried out in five stages as illustrated in Figure 1.1 and described below.
Phase 1: Research Agricultural UAS Applications

The first phase of the study consisted of a comprehensive literature review of agricultural UAS, augmented by interviews of UAS subject matter experts at RAND. Findings from this phase indicate that agricultural UAS tasks can be crudely classified into two categories: surveillance, employing UAS-mounted sensors for early detection of crops and soil stress conditions; and use of UAS platforms for aerial delivery of pesticide, fertilizer, and as this study showed—delivery of biological control measures and sound. Chapter 2, which provides background information on UAS technology in general, and potential agricultural applications in particular, describes this research phase. Appendix A provides background information on RS in agriculture and describes how sensors mounted atop UAS can collect accurate and timely agricultural data.

Phase 2: Identify Key Agricultural Challenges in Africa for Analysis

This study focuses on a small number of agricultural problems that strongly impact the African agricultural landscape. The following criteria were used to select the problems.

- Issue is unique to Africa and poses a serious concern, such as the endemic pests;
- Specific use considered is particularly beneficial for the small agricultural plots that characterize the African landscape;
- Problem is faced by several countries that share one or more characteristics;
- Might be addressed by UAS.
Based on the literature and interviews with SMEs, and consistent with these criteria, the study targets eradication of the Tsetse fly and the human–wildlife conflict with the Red-Billed Quelea bird (covered in detail in Chapters 3 and 4, respectively).

Several other agricultural challenges in Africa also meet the selection criteria (for example, the need for judicious use of inputs can be informed by the monitoring of crop and soil health status by sensors mounted on UAS platforms). In addition, UAS can perform other tasks (crop dusting, dispersing fertilizers and pesticides\textsuperscript{xvi}). However, the methodologies proposed for determining whether UAS technology can help mitigate the Tsetse and Quelea challenges can be used in future assessments of UAS for other agricultural challenges in Africa, or elsewhere.

**Phase 3: Match UAS Technology Specs with Agricultural Requirements, and Assess UAS Performance against Comparable Technologies Used for Similar Missions**

The third stage of the study assessed if, and to what extent, UAS technology may address the agricultural challenges identified in phase 2. The assessment used multiple methods. First, as described in Chapter 3, a systems-engineering approach was used to analyze the compatibility of UAS for mitigating the Tsetse fly problem. To illustrate how such technology can operate in a local African context, the study conducted a vignette analysis examining a pilot program in Senegal. Second, to examine whether UAS can potentially be suitable for Quelea bird control, in-depth interviews were conducted with prominent Quelea and UAS SMEs. Chapter 4 describes in detail these interviews and the findings that emerged from them.

**Phase 4: Identify Key Drivers/Barriers to Adoption of Agricultural UAS in Africa**

The fourth phase of the study marked the transition from technical assessment to non-technical adoption analysis. Literature suggests that technical aspects of technological innovations constitute only a small part of the potential obstacles to their adoption. Multiple factors, and the complex relationship between them, determine if and how new technology applications will be adopted.\textsuperscript{xvi} The combination of these factors creates the complex policy, political, social, and economic environment in which technology adoption occurs. Thus, even given a need and a theoretical match between the technology and the proposed application, the adoption and implementation of UAS may not be straightforward for many African countries. Other factors can either promote or hinder these processes.

Phase 4 included multiple tasks. Chapter 4 focuses on the Quelea problem. Drawing on a field study in Kenya that included a survey of smallholder farmers as well as interviews with diverse stakeholders (SMEs, government officials, NGOs and additional farmers), the chapter considers the technical, economic, political and cultural issues that may affect the adoption of agricultural UAS for this purpose.

Chapter 4 examines only one application of UAS—control of the pest Quelea bird—and only in several counties in Kenya. Thus its findings cannot be appropriately generalized to assess the feasibility of using UAS in other agricultural missions across Africa. Addressing this limitation, Chapters 5–10 assessed to what extent non-technological drivers and barriers may promote or hinder the processes of adoption of
UAS for agriculture in general. Chapter 5 introduces the framework and subsequently Chapters 6–9 populate the different pillars comprising it.

- **Chapter 5. Framework**—Reviews the literature on technology adoption and proposes a novel framework to assess the likelihood of UAS adoption in African agriculture. Subsequent chapters focus on specific elements of the framework.
- **Chapter 6. Innovative capacity & technical literacy of the workforce**—Examines whether a country’s has innovative capacity to develop UAS domestically; if its international standing enables it to import this dual-use civilian-military technology from abroad; and whether its workforce is technically literate to effectively employ UAS.
- **Chapter 7. Affordability & economic viability**—Explores from a national wealth perspective whether countries can afford to invest in or acquire UAS technology.
- **Chapter 8. Governance & institutional capacity**—Assesses from an institutional and governance perspective inter-country variation in the likelihood of successfully adopting agricultural UAS.
- **Chapter 9. Social & cultural acceptance**—discusses the influence of cultural and social norms on technology adoption and assesses the extent to which these factors may affect the likelihood of adopting UAS for agriculture in Africa.

**Phase 5: Develop a Framework to Assess the Feasibility of Adopting Agricultural UAS in Africa, Explore Inter-Country Variations, and Suggest Steps That Policy-Makers Can Take to Overcome Obstacles to Successful Adoption**

Chapter 10 combined the findings from Chapters 6–9 to produce a novel analytical framework for assessing the feasibility of adopting agricultural UAS technology in Africa. The strengths of this framework are its modularity, transparency and comprehensiveness. The framework is applied to 36 African countries, and inter-country variation is exploited to suggest in which of these countries UAS adoption—for any agricultural purpose—is more or less likely and under what circumstances.

Chapter 11 proposes concrete recommendations that can aid policymakers interested in promoting agricultural UAS in Africa capitalize on the main drivers of technological adoption and address the key obstacles to it.

This study provides an original contribution in three important ways. First, it proposes novel agriculture uses of UAS technologies in two yet untapped areas—eradication of Tsetse flies and control of Quelea flocks. Second, it is uniquely focused on evaluating the potential feasibility of UAS adoption across Africa. Finally, the research is interdisciplinary, integrating the fields of agriculture, UAS, and technology adoption to address this policy challenge. The study results suggest a vital exploratory step for policymakers, agricultural experts, international organizations, and aid agencies in exploring use of UAS for agriculture in Africa as a way to promote food security.
Chapter 2. Background: Unmanned Aerial Systems (UAS)

2.1 Introduction

Unmanned Aerial Systems (UAS) include the more narrowly defined types of unmanned aircraft (UA), Unmanned Aerial Vehicles (UAVs) and remotely piloted aircrafts (RPAs), and are often inaccurately referred to as “drones.” However, while all these unmanned aircraft represent air vehicles that do not carry human operators onboard (but in instead either fly autonomously or are remotely piloted), are expendable or recoverable, and can carry various payloads, the term UAS describes far more complex systems.\textsuperscript{xlviii}

Originally, UAS were developed for military applications that were too “dull, dirty or dangerous”\textsuperscript{xlvi} for manned aircraft. The attributes that made the use of unmanned aircraft preferable to manned ones are, in the case of the dull, the better sustained alertness of machines over that of human pilots and, for the dirty and the dangerous, lower political and human cost if the mission is lost, and greater probability that the mission would be successful.\textsuperscript{1} These benefits have even crowned this technology as one of the most promising innovations of our times.\textsuperscript{ii} The Teal Group, for example, predicts that “Unmanned Aerial Vehicles continue as the most dynamic growth sector of the world aerospace industry this decade.”\textsuperscript{xlii}

In recent years, a growing number of countries have been purchasing and developing UAS not only for military purposes but also for civilian applications.\textsuperscript{iii} Experts anticipate a rise in existing and potential civilian UAS uses in various industries including nonmilitary security missions (policing, firefighting, surveillance of pipeline/power lines); filmmaking; search and rescue; disaster relief; conservation of wildlife; scientific research; and multiple agricultural applications such as scouting, mapping and aerial spraying.

The objective of this chapter is threefold: first, provide an overview of UAS technology; second, classify civilian UAS according to their characteristics, and third, introduce agricultural UAS applications. The information presented in this chapter is central to answering the first research question of this study. Specifically, it will help analyze whether some of Africa’s key agricultural challenges can be mitigated by UAS technology, and if yes—by which type.

The remained of this chapter is organized as follows. Section 2.2 delineates the history of UAS development. Section 2.3 describes the different technological features of UAS. Section 2.4 classifies civilian UAS according to predetermined categories and provides examples of common UAS currently employed in civilians missions. Section 2.5 describes the key technical challenges associated with UAS, with an emphasis on civilian systems. Section 2.6 reviews recent UAS applications for agricultural missions. Section 2.7 summarizes the chapter and ties it in with the rest of the analysis.
2.2 UAS History

Predecessors of current UAS technology have been around for over 150 years. The first recorded use of a UA was Austria’s attack on Venice in 1849 employing 200 pilotless balloons mounted with bombs.\textsuperscript{lv} In 1882, in the midst of the U.S. Civil War, both Confederate and Union forces used unmanned aircraft for reconnaissance and bombing. During the Spanish-American War in 1898, the U.S. military fitted a camera to a kite, producing the first ever aerial reconnaissance photos.\textsuperscript{lv}

Development of pilotless aircraft continued throughout World War I. The earliest attempt at a powered UA was A. M. Low’s “Aerial Target” of 1916. The first target UA was the “Bug”—a pilotless aerial torpedo that would drop and explode at a particular, preset time, was developed in 1917 by the Dayton-Wright Airplane Company. Simultaneously, Elmer Sperry began construction of the radio-controlled “Aerial Torpedo” or “Flying Bomb,” which was able to fly 50 miles carrying a 300 lb. bomb.\textsuperscript{lvii}

In the 1930s, the British Royal Navy developed a primitive, radio-controlled UAV: the Queen Bee. The Bee, which could be landed for future reuse and flew at 100 mph, served as aerial target practice for British pilots.\textsuperscript{lviii} The United States developed similar aircraft for the same purpose.\textsuperscript{lxi}

During World War II, Nazi Germany developed a UA to be used against nonmilitary targets. The Revenge Weapon 1, an unmanned flying bomb also known as the V-1, could reach speeds of almost 500 mph, carry 2,000 lb. of explosives and travel 150 miles. In towns and cities across England, the V-1 was responsible for more than 900 civilian deaths and 35,000 injured civilians.

The modern birth of U.S. UA, at the time called remotely-piloted vehicle (RPV), began in 1959 when the United States Air Force (USAF), concerned over the risk of losing pilots in hostile territory, initiated a plan for unmanned flights. The plan was officially launched in 1960 under the code name “Red Wagon” immediately after Francis Gary Powers and his U-2 were shot down over the Soviet Union. The first time that the United States used UA for combat in the Vietnam War was August 1964.\textsuperscript{lxi}

During the 1960s and 70s, the United States flew more than 34,000 surveillance flights mostly employing the AQM-34 Ryan Firebee and Lightning Bugs, RCA launched from host airplanes.\textsuperscript{lx} In the late 1970s and 1980s, Israel developed the Scout and the Pioneer, which represented a shift toward the lighter, glider-type model of UA in use today. The small size of these UA made them relatively inexpensive to produce and difficult to shoot down.\textsuperscript{lxii} The United States acquired Pioneer UA from Israel and used them in the Gulf War in 1991.\textsuperscript{lxii}

In the 1990s, the MQ-1 Predator was developed introducing a new class of UAS—unmanned combat air vehicles (UCAV). Although UCAVs are out of the scope of this study, it is important to note that such aircraft have been employed in thousands of missions globally, primarily in the war Afghanistan.

The 1990s also marked the beginning of development of civilian UAS. The earliest documentation of civilian UAS applications were carried out by Tomlins, Lee and Manore who used a hobby-grade model
aircraft and later a custom-designed small UAS (sUAS) to gather environmental data. In his pioneer research, Tomlins identified as many as 46 environmental applications suitable for sUAS.\textsuperscript{lxii} NASA then emerged as leader in this field with the ERAST (Environmental Research Aircraft and Sensor Technology) project, which included the development of high altitude, high endurance UAS designed to conduct environmental measurements, and brought about the development of the UAS Helios, Proteus, Altus, and Pathfinder.\textsuperscript{lxiv} In the area of agriculture, UAS have been employed for crop dusting as early as in the 1980s. Since then, and especially in the last decade, UAS use in agriculture has expanded in two main spheres: aerial application over agricultural lands, and remote sensing,\textsuperscript{lxv} as explained in Section 2.6.

While civilian use of UAS is considered still in its infancy, experts predict increased role for the technology in the near- and medium-term future.\textsuperscript{lxvi} For example, the Association for Unmanned Vehicle Systems International (AUVSI) estimates that the market for UAS in 2013 stood at $11.3bn, and has the potential to grow to over $140bn within the next 10 years subject to regulatory approvals.\textsuperscript{lxvii} Anticipated expansion of UAS into a myriad of public, private, and commercial missions, in addition to agriculture, include:

- Wildlife conservation (surveying wildlife; monitoring and mapping terrestrial and aquatic ecosystems; supporting enforcement of protected areas e.g., by detecting locating poachers, and relaying accurate and timely intelligence to authorities).\textsuperscript{lxviii}
- Law enforcement and various types of police work (border patrol, survey damage of car accidents; aid in pursuit of suspects; surveillance; respond to alarm calls at night to search for break-in points on roofs;\textsuperscript{lxix} and high-speed police chases\textsuperscript{lx}).
- Reconnaissance after natural disasters (in cases of fire, flood, hurricane, mud slides, earthquakes, volcano eruptions and other).\textsuperscript{lx}
- Inspection of infrastructure (power lines, pipelines, tree mapping to analyze where to place infrastructure\textsuperscript{lxii}).
- Oil, gas and mineral exploration and production.
- Disaster relief (e.g., food aid delivery to besieged areas where manned cargo planes are too vulnerable to anti-aircraft fire, as has been proposed in Syria\textsuperscript{lxiii}).
- Search and Rescue.
- Weather monitoring.
- Motion picture filmmaking, sports photography and cinematography.

2.3 Main Features of UAS Technology

According to the U.S. Department of Defense, UAS is “that system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft.”\textsuperscript{lxiv} Like any other complex system, UAS are composed of a series of major subsystems, including all the equipment and personnel necessary to support the UA. In general, UAS are considered to be comprised of the following\textsuperscript{lxv}

- Unmanned aircraft (UA);
• Communication systems/Data Link;
• Ground Control Station (C3);
• Mission payload modules;
• Navigation gear; and
• Miscellaneous launch, recovery, and ground support equipment.

Many of these subsystems conceptually map to standard air vehicle subsystems. It is arguable that, as with a manned system, the ground station or command and control element is not really integral to the system or necessary when UAS are more autonomous. The software of the UAS guidance system consists of control systems for stabilization and navigation, and a degree of decision making and sensor processing that dictates the degree of autonomy. This section describes a sub-set of features of these subsystems, including the UA, basic avionic functions, degree of autonomy, data link and C3.

Unmanned Aircraft (UA)

The U.S. defines unmanned aircraft (UA) as “An aircraft that does not carry a human operator and is capable of flight with or without human remote control.”Mission, environment and intended aircraft performance attributes are key drivers for UA structures in the same sense as for manned aircraft. The characteristics of the UA itself, including shape, size, endurance and means of control, determine the classification outcomes (as will be presented in detail in Section 2.4). Hence, it is useful to review these attributes beforehand.

First, UA can be distinguished according to the means by which they are being controlled: ground-control or remote piloting, semi-autonomous, or autonomous flying based on pre-programmed flight plans or more complex dynamic automation systems. Moreover, UA can be broadly divided into three categories according to their endurance: low, medium and high endurance. High endurance demands a high fuel fraction which can result in a tradeoff with payload fraction. In addition, UA can carry a payload which is the equipment installed to perform a specific task. UA come in a variety of configurations with different shapes, sizes and capabilities. They may have a wingspan as large as a Boeing 737 or smaller than a radio-controlled model airplane. UA typically fall into one of the following four categories according to their characteristics (aerodynamic configuration, size, etc.):

• **Fixed-wing UA:** unmanned airplanes (with wings) that require a runway to take-off and land. Fixed-wing UA generally have long endurance and can fly at high cruising speeds. Different wing designs affect lateral stability, especially in the cases of SUAS and MAV (Micro or Miniature) that use high aspect ratio wings and are therefore sensitive to lightly turbulent air. This can pose a challenge when such classes of UAS are employed for ISR tasks.

• **Rotary-wing UA:** also called rotorcraft UAVs or vertical take-off and landing (VTOL) UAVs. Their primary advantages are hovering capability and high maneuverability which make them useful for many robotic missions. In military applications, the objective is that small VTOLs would be positioned in a place where they can observe the scene where there is enemy activity of interest. The small VTOL can then observe movement (change detection) and notify the human user by sending a picture of the object that has moved (changed). This reduces the fuel required to operate, increases the time on station significantly and eliminates the users need to “watch”
the video screen. This feature can also be extremely useful in civilian applications for example in monitoring of wildlife, infrastructure, border control and others. A rotorcraft UA may have different configurations, with main and tail rotors (conventional helicopter), coaxial rotors, tandem rotors; multi-rotors, etc.

- **Blimps**: for example balloons and airships that are lighter than air and have long endurance, fly at low speeds, and generally are large sized.
- **Flapping-wing UA**: have flexible and/or morphing small wings inspired by birds and flying insects. There are also some other hybrid configurations or convertible configurations, which can take-off vertically and tilt their rotors or body and fly like airplanes (for example the Bell Eagle Eye UAV).

### Basic Avionics Architecture

The avionics of a UAS has to fulfill the role of the avionics on a traditional aircraft as well as accommodate the level of autonomy that the UAS is desired to have. Ongoing efforts seek to make UAS increasingly autonomous but traditionally UAS have had limited autonomy particularly in takeoff and landing. This necessitates a datalink and ground station for navigation and control in at least these flight phases. The rest of the avionics architecture consists of the flight computer, sensors and actuators (Figure 2.1).

![Figure 2.1 Basic UAS Avionics Architecture](image)

**Flight Computer**

The flight computer, also known as the aircraft control system, is used to fly the UAS, utilizing either a two-way data link (radio) for remote control or onboard computer (with GPS navigation) connected to the aircraft control system. It includes the control station(s), communication links, data terminal(s), launch and recovery systems, ground support and air traffic control interface.

**Actuators**

Actuators are used as a mechanism to induce or control motion in mechanical systems. These devices are operated by a source of energy, typically electric current, hydraulic fluid pressure, or pneumatic
pressure, to transform an input signal (usually electrical) into motion. Actuators are used in flight control, including stabilization, autopilots and vibration control.

Payload
Payload is the equipment installed to perform a specific task, and include for example high and low resolution cameras or video cameras, day and night reconnaissance equipment, warfare machinery weapons, cargo and generally any equipment required for the mission the UAV is designed to perform. In agriculture, the payload serves usually for surveillance (using cameras and various optical and non-optical sensors), or delivery (e.g., pesticide, fertilizer).

At the very basic level, payloads require space, weight and power allocation. However, certain types of payloads may also necessitate access to UAS data on the UA position, altitude and speed. It is important to provide UAS data to the payload in a manner such that the failure of the payload cannot impact the safety of the UAS’ own systems.

Sensors
Sensors provide information needed to operate the aircraft, and collect valuable information related to the mission at hand. A minimal autopilot system includes attitude sensors and onboard processor. Common sensors are radar, photo or video camera, IR scanners or electronic intelligence (ELINT). Sensors are required to detect and identify targets.

Data Link and Ground Station Command, Control, and Communications (C3)
Command, Control, and Communications (C3)
The command and control function of UAS is accomplished by a combination of planning, personnel, equipment, communications, navigation and technical procedures. As shown in Figure 2.2, A UAS may operate within radio frequency (RF) line-of-sight (LOS), or beyond line-of-sight (BLOS). Technologies and standard operating procedures (SOPs) related to command, control and communication of UAS are divided into one of these two categories. Specifically, LOS is associated with command and control (C2) and BLOS is linked to air traffic control (ATC).
LOS and BLOS systems overlap to an extent both in technologies and in the classes of UAS that can operate within these areas, as illustrated in Figure 2.3. The LOS section includes all types of unmanned aircraft (low, medium and high endurance), but the BLOS section includes primarily high-endurance and a few medium-endurance UAS capable of operating beyond the RF LOS of the pilot in command. In BLOS command and control communications with UAS, satellite communications (SATCOM) are used. Communications with UAS are done primarily through the use of RF.

**Figure 2.3 BLOS Operations Are Subset of LOS Operations**

Data Link

A UAS data link typically consists of an RF transmitter and a receiver, an antenna, and modems to link these parts with the sensor systems. For UAS, data links serve the important function of maintaining communications between the ground control station or satellite and the UAS. Efforts to standardize data links have resulted in the use of the common data link (CDL), typically a wideband link, jam...
resistant and secure. These links connect the ground station with the UAS via direct, point-to-point links or use SATCOM.\textsuperscript{xcv}

\textbf{UAS Degree of Autonomy}

There are three forms of control that an operator may exert over the aircraft: Ground-control or remote piloting; semi-autonomous; and autonomous.

\textbf{Ground Control}

Ground-controlled UAS, also known as RPAs, require constant input from the operator. In essence, RPAs are sophisticated radio-controlled (RC) aircraft that use the same basic techniques that are familiar to the RC hobbyists. Most military UAS flying today (MQ-1 Predators, MQ-9 Reapers, and RQ-11 Ravens) are still purely remotely piloted (also known as stick-and-rudder). Flying waypoints by themselves, the Global Hawks are an exception in the military. Literature however indicates that there are serious attempts at making systems gradually more autonomous.\textsuperscript{xcvi}

\textbf{Semi-Autonomous}

The use of guidance systems is now common. Semi-autonomous flight can be defined as requiring ground input during critical portions of the flight such as take-off, landing, and in the case of armed UAS, weapons employment. The operator must assume full control of the aircraft during pre-flight, take-off, landing, and when operating near base, but once airborne an autopilot function can be engaged and the aircraft will follow a set of preprogrammed waypoints. The operator is responsible for the UA throughout the operation, however, and can assume control at any time.\textsuperscript{xcvi}

\textbf{Fully Autonomous}

In theory, autonomous flight requires no human input in order to carry out a mission following the decision to take-off. Because under autonomous control, on-board computer is in control rather than a human being, such systems require a sophisticated autopilot, allowing it the UAS to fly itself on programmed flight paths without human interference for almost all the mission (except for monitoring). An autonomous UAS is able to monitor and assess its health, status and configuration.\textsuperscript{xcvii}

\textbf{2.4 Civilian UAS Classification}

The long pedigree of UAS military applications has led to well-established classification criteria for military UAS. Only recently researchers and industry have sought to classify civilian UAS in a similar manner. This section presents civilian UAS classification, which generally follows existing military criteria, based upon generally accepted nomenclature in the civilian realm.\textsuperscript{xcviii}

Table 2.1 summarizes civilian UAS classification by these characteristics. A more detailed explanation of each class is presented below. This classification is based on the following characteristics:

- \textit{Weight}: the maximum gross takeoff weight of the UA with the payload.
• **Altitude**: UAS category are defined by the range within they can fly:
  - High altitude: 60,000 ft.
  - Medium altitude: 18,000–60,000 ft.
  - Low altitude: up to 18,000 ft.
  - Very low altitude: below 1,000 ft.

• **Endurance**: The most sophisticated types of UAS, characterized by high size and capabilities, also have the highest endurance. Such aircraft can operate in a range of more than 300 miles, or that can stay in the air for >20 hours.

### Table 2.1 Summary of Civilian UAS Classification

<table>
<thead>
<tr>
<th>Category</th>
<th>Payload Weight</th>
<th>Maximum Altitude (ft.)</th>
<th>Normal Operating Altitude (ft.)</th>
<th>Mission Range</th>
<th>Endurance</th>
<th>UAS Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAV/NAV</td>
<td>0.6 oz.–3 lb.</td>
<td>~1,000</td>
<td>~500</td>
<td>LOS</td>
<td>Up to 1 hour</td>
<td>Wasp AE</td>
</tr>
<tr>
<td>VTOL</td>
<td>3–180 lb.</td>
<td>~15,000</td>
<td>~6,000</td>
<td>Mostly LOS</td>
<td>20–100 minutes</td>
<td>Yamaha Remax</td>
</tr>
<tr>
<td>LASE</td>
<td>4–11 lb.</td>
<td>~10,000</td>
<td>~5,000</td>
<td>LOS</td>
<td>1–2 hours</td>
<td>Silver Fox</td>
</tr>
<tr>
<td>LALE</td>
<td>~10 lb.</td>
<td>~15,000</td>
<td>~10,000</td>
<td>BLOS</td>
<td>~15 hours</td>
<td>Scan Eagle</td>
</tr>
<tr>
<td>MALE</td>
<td>~2,000 lb.</td>
<td>~40,000</td>
<td>18,000–30,000</td>
<td>LOS &amp; BLOS</td>
<td>~24 hours</td>
<td>Ikhana</td>
</tr>
<tr>
<td>HALE</td>
<td>~2,000 lb.</td>
<td>~70,000</td>
<td>~60,000</td>
<td>BLOS</td>
<td>30–336 hours</td>
<td>Global Hawk</td>
</tr>
</tbody>
</table>

**MAV (Micro or Miniature) or NAV (Nano) Air Vehicles**

MAVs are minimal size aircraft that enable their military versions to be transported within individual soldiers’ backpacks. Expected civilian uses for example in agriculture include short surveillance missions that individual farmers can conduct independently with handheld platforms. These aircraft operate at very low altitudes, typically lower than 1,000 ft. Their battery capacity is usually limited restricting flight durations to 5–30 minutes. Recent developments however have improved their endurance, e.g., AeroVironment’s “Wasp AE” MAV can fly for 50 minutes at an altitude of 500 ft.

**NAVs** are extremely small, low-altitude, short-duration UAS platforms designed to enhance situational awareness in areas where they may go unobserved. A notable example is AeroVironment’s “Nano Hummingbird,” its ongoing development was sponsored through a DARPA sponsored research contract, which represents a new class of aircraft systems capable of indoor and outdoor operation. Employing biological mimicry at an extremely small scale, the objective of the Hummingbird is to provide new reconnaissance and surveillance capabilities in urban environments. It is the size of a small bird (e.g., weight of 0.6 ounces, and wingspan of 6.3 inches), and it can climb and descend vertically, fly in all horizontal directions, is equipped with a small video camera, and has a flight endurance of eight minutes.
VTOL (Vertical Take-Off & Landing)/Rotary Wing

These aircraft require no takeoff or landing run, and are therefore preferable in situation when terrain is limited or when hovering capability is required. VTOL aircraft operate at varying altitudes depending on their mission profile, but predominantly fly at low altitudes. High power requirements for hovering limit the flight durations for VTOLs, except in the largest sizes where increased lifting capabilities accommodate large fuel capacity.

Most current VTOLs are small, operating with electric motors from rechargeable batteries limiting flight durations to less than one hour. They also have limited sensor payload capabilities. Nevertheless, recent developments in the miniaturization of sensors make these platforms valuable in quick analysis situations. VTOL UAS have been used in real time crises in the civilian realm to support structure damage analysis and rescue operations in a complex urban structure environment. Their ease of maneuverability makes VTOL more suitable to navigate through at low altitude than can fix-wing aircraft. Furthermore, these platforms are considered to be potentially useful for law enforcement operations, where a low-altitude, hovering capability with image data capture could be helpful for learning about an incident. Finally, they can contribute to scientific research and agricultural applications that require hovering capacity over a fixed survey plot of relatively small size.

For most VTOL UAS, LOS operations are the common control method. Missions for “quick-look” analysis can be readily accomplished with a one- or two-person crew, making these platforms cost-effective for short-duration observational needs. There are small and medium-size versions of VTOLs. For instance, Draganflyer X6, developed by Draganfly Innovations, is a 2.2 lb. tri-rotor platform capable of lofting payloads of 17 oz. to altitudes of 7,900 ft. of up to 20 minute-flights.
An example of mid-sized, commercially used VTOL is the Yamaha RMAX, a two cycle/two cylinder UAS helicopter with a 62 lb. load capacity, 10 ft. main rotor diameter platform with remote control systems via a LOS ground control station. It has been mainly employed for agricultural spraying in Japan, Australia and other countries, and can support remote sensing operations.

Figure 2.5. Draganflyer X6 (left); Yamaha RMAX

SOURCES: DeDeaux (left); Rangoa and Laliberteb, et al

LA (Low Altitude)
These are small UAS (sUAS) that take a variety of sizes and configurations, from back-packable, hand-launched to catapult-launch platforms. Such aircraft can be divided into three types:

1. **LASE (Low Altitude, Short-Endurance):** LASE aircraft obviate the need for runways with aircraft optimized for easy field deployment/recovery and transport. The UA component of these systems typically weighs 4-11 lb. with wingspans smaller than 10 ft. to enable launching from miniature catapult systems, or by hand. Compromises between weight and capability tend to reduce endurance and communication ranges to 1–2 hours and within a few miles of ground stations.

2. **LASE Close:** Such aircraft are sUAS whose aircraft require runways, but whose larger size and weight confer increased capabilities. These systems operate at up to an altitude of 5,000 and may remain aloft for multiple hours. Recent developments however exceed the altitude and endurance limits.

3. **LALE (Low Altitude, Long Endurance):** These aircraft represent the upper end of the sUAS weight designation by the U.S. FAA. Such UAS may carry payloads of several lb. at altitudes of a few thousand feet for extended periods.

The LALE/LASE UAS are relatively simple to operate, with flight controls similar to RC models and simplified ground-control stations that allow for small crews. Most of the remote sensing systems are small, simplified cameras or streaming video cameras in either daylight (color or black/white (B/W)) or infrared (B/W) video provided of surface objects being imaged, although increased capabilities are enabling direct image geo-referencing in some of these systems.
Some of the more common, low-cost LASE/LALE platforms currently in use are lightweight and can be hand-launched, allowing versatile field condition operations in areas without solid surface runways. The disadvantage of hand-launch platforms is their relative short-duration operational capabilities of 45 minutes–2 hour, and a reduced payload capacity.

An example of a LASE is the Silver Fox, designed to function primarily as an expendable, over-the-horizon surveillance tool. It can be launched from ships or from land. A new department of LASE/LALE UAS are solar UAS, for example Sunlink-5 which can carry payloads up to 11 pounds and generate up to 100W of electrical power via their photovoltaic cells. Their maximum altitude is 10,000 ft., and they can fly for up to eight hours. According to the developers, such UAS are designed for such uses as wireless communications, agriculture, land survey, wildfire or wildlife monitoring, and border patrol.

**Figure 2.6. Silver Fox**

![Silver Fox](source)


MALE (Medium Altitude, Long Endurance)

Such aircraft are typically much larger than low-altitude classes of UAS, operating at altitudes up to 30,000 ft. on flights hundreds of miles away from their ground stations and lasting many hours. MALE UAS platforms play a significant role in strategic operations in defense and are also seeing increased use within a few civil applications areas for example NASA’s Ikhana UAS, a Predator-B derivative, which supports NASA’s Science Mission Directorate of the Earth Science Division. It also completed over 20 fire-imaging missions in the western USA, showcasing the utility of UAS to support both scientific data collection and disaster monitoring capabilities.

The Ikhana’s 65 ft. wingspan can lift payloads of nearly 440 lb. internally, as well as external loads of 1,980 lb. The aircraft is capable of reaching altitudes above 40,000 ft., but with limited endurance at that altitude. The aircraft performance is optimized at 18,000–30,000 ft., where it is capable of about 24-hour missions.
Another example MALE UAS is the NASA Sensor Integrated Environmental Remote Research Aircraft (SIERRA) which can perform remote sensing and atmospheric sampling missions in isolated and often inaccessible regions. Developed by the U.S. Naval Research Laboratory and NASA’s Ames Research Center, SIERRA has a gross takeoff weight of 400 lb. and carry 100 lb. payload on flights lasting up to 10 hours, at a maximum altitude of 12,000 ft. It has supported several airborne science data collection campaigns, including measurement of sea-ice roughness via RS to try to detect basic changes in ice conditions such as thickness and ice age in Norway in 2009; autonomously detecting and locating methane releases from petroleum production as part of monitoring greenhouse gas mission in Nevada in 2011; and carrying out hyperspectral bio-optical observations to assess core physiological and biogeochemical variables in sea-grass and tropical coral habitats in Florida and in the Tobago.

Figure 2.7. Ikhana (left); and SIERRA

HALE (High Altitude, Long Endurance)

These are the largest and most complex of the UAS, with aircraft larger than many general-aviation manned aircraft. Such UAS can fly at altitudes of 65,000 ft. or higher on missions that extend thousands of miles. Some HALE aircraft have flight durations over 30 hours, and have set records for altitude and flight duration.

Outside of the U.S. Department of Defense, the major civilian elements that have employed HALE UAS to support science have been NASA and NOAA. Their scientific objectives necessitate the use of HALE platforms to collect information at regional and global scales to allow assessments of climate variable impacts across broad regions of the globe and to support satellite observations at spatial and temporal scales, not achievable with less able manned or unmanned platforms. Because of their operational uniqueness and capabilities, these platforms are prohibitively expensive for most users; they are therefore used to support large investigative science campaigns, rather than smaller, localized assessments where other categories of UAS or manned platforms prove more cost-effective.

One such platform is Northrup-Grumman’s Global Hawk which has been supporting several scientific remote sensing campaigns since 2008. The Global Hawk has an operating altitude of 65,000 ft., a flight
endurance of over 30 hours, and carries a payload of 1,650 lb. for a range of over 10,000 miles. The platform has compartments that can house over 10 different instruments, supporting multiple science instrumentation measurement capabilities.

For instance, during the 2010 Global Hawk Pacific Mission (GloPac), 10 instruments supported measurements of trace gases, aerosols and dynamics of the upper troposphere and lower stratosphere. In the 2011 Winter Storms and Pacific Atmospheric Rivers (WISPAR) campaigns NOAA led a series of observations during long-duration NASA Global Hawk flights over the Pacific Ocean that explored atmospheric rivers and Arctic weather and collected targeted observations designed to improve operational weather forecasts.

Very long-duration platforms, such as the Qinetiq Zephyr, are built of carbon-fiber composites, with lithium sulfur batteries taking energy from the solar cells that compose the upper surface of the wing. These platforms are considered to have higher civilian potential in supporting regionalized, long-duration observations. The Qinetiq Zephyr can fly for over 336 hours, or two weeks. Its maximum altitude is 69,000 ft. and a payload of 5.5 lb.\(^{\text{cxvii}}\).

**Figure 2.8. Global Hawk RQ-4 (left) and Qinetiq Zephyr**

![Figure 2.8. Global Hawk RQ-4 (left) and Qinetiq Zephyr](source)

**SOURCE: NASA**

### 2.5 Key Technical Challenges Associated with UAS

UAS are associated with multiple challenges, including potential security and privacy risks, public safety, public opinion, costs and others. This section reviews only a sub-set of technical issues that may hinder widespread use of UAS in civilian airspace, and hence are of prime importance when considering adoption of agricultural UAS.

**Sense-and-Avoid**

One of the biggest limitations to the widespread use of unmanned vehicles in civilian airspace has been the Sense-and-Avoid problem\(^{\text{cxvii}}\). In manned civilian aviation, “See and-Avoid” is the primary mechanism by which piloted aircraft avoid collisions with each other. Obviously this is impractical for widespread use of unmanned vehicles, so they must achieve an equivalent level of safety to that of...
manned aircraft operations. Significant research is currently being conducted on the UAS Sense and-Avoid problem. Active solutions include the use of radar or Traffic Collision Avoidance System (TCAS) to detect collision threats, however such solutions require high amounts of electrical power, and are heavy (more than 44 lb.). Passive solutions include the use of machine vision, which indeed reduces the power requirement, yet requires high computational capability.

Lost Link Procedures

UAS need to be equipped with a means of automatic recovery in the event of a lost link. There are many acceptable approaches to satisfy the requirement.23

Data Links Challenges

Designing aeronautical wireless data links is challenging due to the large distances that they need to cover and the high-speed of the aircrafts. These along with the limited availability of RF spectrum affect the performance of the data link. New data links need to be developed for commercial and civilian UAS before they share non-segregated airspace and these need to address the aforementioned challenges.24

Security Issues of C3 Technology and Operations

UAS are different than conventional aircraft in the sense that a pilot onboard has “immediate control” of the aircraft. However, in case of UAS, there is a medium—the data link—between the pilot at the ground control station and the aircraft. The data link (and ATC) is susceptible to security threats including spoofing, hijacking, and jamming. Theoretically, a hacker can create false UAS signals, jam the data link or even hi-jack the data link and take the control of UAS. Because data links are vital to the safety and seamless functioning of the UAS, this issue is important. Currently, several security features can be built into the system (e.g., design the system such that the aircraft acknowledges all commands it receives).25 While the military uses secured data links like CDL and has other built-in security functions, no such permanent solution is available for civilian market at the moment.26

Communications Issues

One consideration that determines whether a UAS of a certain class can or cannot perform a task is the combination the range and altitude requirements of the task, and specifically the LOS Communication Range. In short, the lower the aircraft flies, the shorter this range is. To provide some context to this limitation, I calculated the LOS communication range versus altitude27 and matched these calculations to the attributes of different UAS classes, as described in Section 2.4. These calculations are based several assumptions:

1. Applicable only for missions below 70,000 ft. altitudes;
2. Grazing angle of 3 degrees;
3. No terrain masking;
4. The spherical earth radius \(r_e = 3,443.91 \text{ nm}\) is scaled by a factor of \(4/3 (4,591.88 \text{ nm})\), to account for RF effects (RF signals tend to bend around the earth in the atmosphere);
5. The radio altitude and the target altitude are zero (because it is on the ground).

As shown in Table 2.2 and Figure 2.9, MAV UAS operating at an altitude of 100 ft. (328 meters) are limited in LOS communication range to 5.78 km, or 3.6 miles. A UAS of VTOL class is limited to 80 km in communications range (49.7 miles). Such calculations are pertinent when planning missions, as will become evident in Chapters 3 and 4 which assess the potential compatibility of UAS to help address the Tsetse fly and the Quelea bird problems in Sub-Saharan Africa.

### Table 2.2 UAS Range versus Altitude by Civilian UAS Class

<table>
<thead>
<tr>
<th>Aircraft Altitude (km)</th>
<th>Max Operating Range (km)</th>
<th>Civilian UAS Class</th>
<th>Class Max Altitude (km)</th>
<th>Class Max Range (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>5.78</td>
<td>MAV/NAV</td>
<td>0.30</td>
<td>5.78</td>
</tr>
<tr>
<td>0.50</td>
<td>9.44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>18.68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>36.64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.05</td>
<td>54.77</td>
<td>LASE</td>
<td>3.05</td>
<td>54.77</td>
</tr>
<tr>
<td>3.72</td>
<td>66.03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.00</td>
<td>70.67</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.57</td>
<td>80.01</td>
<td>VTOL, LALE</td>
<td>4.57</td>
<td>80.01</td>
</tr>
<tr>
<td>5.00</td>
<td>86.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.00</td>
<td>102.58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.00</td>
<td>132.71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>161.34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.19</td>
<td>191.28</td>
<td>MALE</td>
<td>12.19</td>
<td>191.28</td>
</tr>
<tr>
<td>14.00</td>
<td>214.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.00</td>
<td>240.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18.00</td>
<td>264.32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21.34</td>
<td>303.10</td>
<td>HALE</td>
<td>21.34</td>
<td>303.10</td>
</tr>
</tbody>
</table>
Several possible solutions may help overcome LOS communication range limitations. First, it is possible to conduct the mission in parts and cover a smaller range every time within these limitations. Otherwise, miniaturization and cost reduction of SATCOM options may enable BLOS communications. Alternatively, cellular networks may provide connectivity to the UAS flying below 10,000 ft. (3 km). In addition, the aircraft can break communications when it drops in altitude to dispense payload (or conduct any other mission), and re-establish communications when it climbs back up. When beyond LOS, the aircraft flies autonomously. This option however has three primary shortcomings. First, automation technology is still maturing and may not be quite ready for such a solution. Moreover, it is associated with higher safety risks. Finally, public perceptions against the concept of an “autonomous drone” may hinder the adoption of this option. A sentiment against “autonomy” was expressed in the open letter against autonomous weapons released July 28, 2015 by leading artificial intelligence and robotics researchers.\textsuperscript{cxxxiv}

**Airspace Integration**

The introduction of UAS into a system that has traditionally been dominated by manned flights creates a number of safety issues, including potential air collisions, ground collisions and system reliability\textsuperscript{cxxxv}. From a regulatory perspective, not having a pilot onboard makes the integration of UAS into the airspace a difficult task, especially when the airspace is busy. Therefore, regulation is concerned with the degree of autonomy of the UAS operated as well as with their range of operation (LOS vs. BLOS).

According to the Federal Aviation Administration (FAA) in the United States, UAS “are inherently different from manned aircraft. Introducing UAS into the nation’s airspace is challenging for both the FAA and aviation community, because the U.S. has the busiest, most complex airspace in the world.”\textsuperscript{cxxxvi} The FAA is taking an incremental approach to safe UAS integration. There are presently two ways to obtain FAA approval for civilian UAS flights.\textsuperscript{cxxxvii}
• Obtain an exemption and a certificate of waiver or authorization in order to perform commercial operations in low-risk, controlled environments.
• Obtain special airworthiness certificate through full description of the UAS, including the engineering procedures, software, configuration and statement where and when it is intended to fly.

In February 2015, the FAA relaxed its requirements pertaining to sUAS (under 55 lb.) and such UAS that conduct non-recreational operations can now fly but only during daylight and within LOS.\textsuperscript{cxxxviii} This rule caps UAS altitude at 500 feet above ground level.

Different countries have different rules governing the national airspace but in general, the United States is considered fairly conservative. For instance, Japan has been encouraging the use of civilian UAS since the 1980s primarily in the agricultural sector, in response to an aging farming population. The country has had lax regulations which allowed for UAS use in agriculture and this technology was even employed in disaster monitoring after the Fukushima nuclear incident.\textsuperscript{cxxx} The current law does not currently prohibit UAS at or below 820 ft. above ground except near airports. However, the country is likely to set restricted areas for UAS around government buildings, nuclear plants, airports and other sensitive areas,\textsuperscript{cxxx} after a small UAS fell onto the roof of the office of Prime Minister Shinzo Abe in April 2015.\textsuperscript{cxxxii}

In Africa, the legal environment on UAS is relatively open slate.\textsuperscript{cxxxii} This may reflect different levels of institutional capacity (including rule of law; as discussed in Chapter 8), or low levels of mechanization, or an airspace that is significantly less congested than that of the United States.

In meetings in Kenya with Government officials from the Ministry of Transport & Infrastructure that is in charge of aviation, they admitted that Kenya has had a legal vacuum around the issue of civilian UAS. However, in response to an incident where a media outlet sought to film a public event using a UAS, the Kenyan government now banned all civilian UAS flights. The Government is currently deliberating the issue and is most likely to follow the U.S. FAA regulation model concerning civilian UAS flights\textsuperscript{1}. It is assumed that as exposure to this technology grows across Africa, legislatures would follow existing legal frameworks ranging from the more restrictive U.S. version to the more permissive Japanese one.

2.6 UAS in Agriculture

Since the first UAS were developed for crop dusting beginning in the 1980s, agricultural uses of this technology have proliferated primarily in in two main areas: delivery or aerial application of pesticides and fertilizers over agricultural lands; and aerial imaging (remote sensing) to support crop field mapping and growth monitoring. Most agricultural UAS are MAVs, fixed-wing or rotary-winged helicopters of low cost, low speed, low ceiling altitude, light weight, low payload weight capability, and short endurance.\textsuperscript{cxxxiii}

\footnote{A more through description of this interview is provided in Chapter 4.}
Predominantly, agricultural UAS applications thus far, and developments in this area, are in the RS domain. UAS mainly perform LARS missions that complement remote RS of high-altitude flights from piloted aircraft and satellite. Such missions typically require low-medium endurance and thus the UAS used are mostly gasoline or methanol-fueled or electric-powered using rechargeable batteries or solar power. While the UAS using rechargeable batteries typically only support short endurance runs, the ones using solar power can potentially provide longer endurance. The UAS for aerial application of pesticide spraying have a higher payload weight requirement but are able to support longer flight endurance.

**Delivery/Aerial Application over Agricultural Lands**

The less researched area of agricultural UAS missions is in delivery or aerial application, including for water, fertilizers and pesticides.

Application of crop production and protection materials is a crucial component of pest management in agriculture. Agricultural application of fertilizers and chemicals is frequently needed at specific times and locations to increase yields or for accurate, site-specific management of crop pests. These applications are typically made through use of ground sprayers, chemigation, or aerial application equipment. While these methods are well suited to large acreage cropping systems, they may become inefficient or cumbersome for small plot production systems that characterize the African landscape. The advantages of UAS over many of the existing technologies in terms of their maneuverability, low operation costs cheaper to operate, safety and accuracy have spur great interest in using and developing UAS for aerial application of materials.

The first attempt at UAS for aerial application took place in 1983 in Japan with the development of the Remote-Controlled Aerial Spraying System (RCASS) by the Yamaha Motor Corporation. This Corporation is a leader in developing and modifying non-military UAS for agricultural applications, starting in Japan with insect pest control in rice paddies, soybeans and wheat and expanding to other areas and uses. Subsequently in 1990, Yamaha’s R50 UAS helicopter emerged with a payload capability of 44 lb. and in 1997, the RMAX was developed. In 2000 the RMAX was equipped with an azimuth and Differential Global Positioning System (DGPS) sensor system.

An important milestone was marked in a 2005 experiment in the United States designed to determine the effectiveness of using a UAS for dispersing pesticides to reduce human disease due to insects. Off-the-shelf Yamaha RMAX UAV outfitted with both liquid and granular pesticide dispersal devices was used, and a series of tests were performed to evaluate the effectiveness of the UAS to perform aerial pesticide delivery. Results showed that overall the UAS pesticide-dispersion system performed reliably.

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2 Chemigation is the injection any chemical such as nitrogen, phosphorus or a pesticide into irrigation water and apply it this way to the land.
Today, Japan uses more than 2,300 small unmanned helicopters to spray difficult to reach rice fields, while also monitoring the health of the crop. In fact, over 90 percent of crop protection in Japan is done utilizing the Yamaha RMAX. The case of Japan is informative for Africa as the average Japanese farm size is 3.7 acres, a size comparable to that of African farms, which are around 2 acres on average. This is in contrast to the United States, in which the average farm size is 441 acres, which may make the use of UAS for aerial application less effective. The reason is that agricultural UAS such as the RMAX have a chemical capacity of 4.25 gallons of liquid compared to 300+ gallons in a manned agricultural aircraft that are being used on U.S. farms. Further, the Yamaha RMAX for example operates at 15 miles per hour (mph) compared to a 160 mph for a manned agricultural aircraft. Finally, the amount of air pushed down to the crop canopy—either from a rotor or from a fixed wing—is exactly proportional to the weight of the aircraft that the air is holding up. A small aircraft—manned or unmanned—does not displace much air. This amount of air is what makes aerial application effective in crop protection. Given these limitations, it is unlikely UAS will be utilized for mass aerial application in the United States in the near future. However, such uses are suitable even in the United States in “niche” circumstances such as small-scale vineyards and specialty crop situations, along with sensory applications.

In fact, vineyards in California’s wine country have already started experimenting with UAS technology for aerial application, not only of fertilizer and pesticides but also for irrigation. The region is characterized by narrow rows and hilly terrain, which pose obstacles for tractors, but not for UAS. As part of University of California trials, the Yamaha RMAX is tested for application of water, as well as pesticides and fertilizers. According to reports on this research, the RMAX should not be compared in this case against manned aircraft but rather against tractor or manual labor. And indeed, as these studies show, UAS compares economically well with trying to get a tractor up hills or resorting to workers carrying backpack sprayers. UAS also could make it easier to deal with problems affecting only a portion of a vineyard. In addition, the RMAX goes about 10 times faster than a tractor, even though it is flying quite slowly at 12 mph while spraying.

UAS can potentially be used for aerial spraying in insecticide application of vectors, particularly mosquitoes (and as studied in Chapter 3, in eradication campaigns against the Tsetse flies which are also vectors of a parasite). In 2009, Huang et al. developed a specific spray system for use on fully autonomous UAS. The team built a low volume spray system for use on the Rotomotion SR200, a VTOL unmanned helicopter powered by a two stroke gasoline engine. It has a main rotor diameter of 118 inches and a maximum payload of 50 lb. Their research showed that a spray system was successfully developed for a UAS application platform. The integration of the spray system with the UAS resulted in an autonomous spray system that can be used for pest management and vector control.

Interestingly, spray UAS helicopters, initially developed for aerial application, have been adapted for agricultural RS. Compared to light weight UAS platforms thus far used solely for LARS, modified unmanned helicopters are more expensive and bigger but as can carry heavier payloads such as high-performance cameras. For example, 20 year ago, in 1994, Yanmar YH300 spray unmanned helicopter was modified to carry a high-definition digital multispectral camera to survey agricultural fields. The
same helicopter was used to monitor crop status for precision agricultural operations. In both cases, the equipment for spraying (chemical tank and nozzles) was removed and an adaptor was installed for mounting the imagery gear.

More recently, in 2011, a Yanmar AYH-3 spray unmanned helicopter was mounted with a hyperspectral imaging sensor to collect information for predicting maize yield and feed quality. The data provided proved accurate for prediction of crop attributes, especially nutritional ones.

**Remote Sensing in Agriculture**

The principles and applications of RS are discussed in detail in Appendix A. It is useful to note here though that in the context of agriculture, RS detects differences in crop growth and soil condition through variations within the spectral responses. This information in turn can be used to identify nutrient deficiencies, diseases, water status, weeds, damages, and plant populations. Specifically, it is useful when it detects changes in remotely sensed reflectance before symptoms become visible to the human eye. The attributes of RS as non-disruptive means to collect systematic, accurate, timely information have become increasingly advantageous as farmers are seeking to embrace modern technologies to increase crop yields and meet growing demand for food on one hand, and dwindling supply on the other.

RS supports general agricultural applications such as monitoring and mapping of soil properties, classification of crop species, crop pest management, plant water stress detection, and monitoring weed control.

Common RS platforms are satellites, airplanes, balloons, helicopters and UAS. A variety of sensors are installed on these platforms including optical and near infrared sensors and RADAR. In recent years, satellite images have been utilized to monitor crop growth and stress, as well as to predict crop yield. However, their use has been limited by poor revisit times, restrictive spatial resolutions, and occasionally cloud cover. RS equipment mounted on piloted airborne systems has been useful for a variety of farming missions albeit limited by high operational complexity, costs, and safety risks.

UAS have several important advantages over other technologies. Primarily, unlike satellites, they allow for independent timing of aerial passes thus avoiding inadequate frequency of satellite surveys or disturbances due to cloud cover conditions. Moreover, they can provide ultra-high spatial resolution to the degree of centimeters. While that may also be true for piloted aircraft, UAS are safer in low altitudes especially under extreme weather. Furthermore, piloted aircraft are often associated with high operational costs and allow less time flexibility as a result of scheduling of flight plans. In addition, UAS can be advantageous in remote areas where piloted aircraft are not widespread. Finally, UAS are less expensive than ground level observation missions.
The area of Low Altitude Remote Sensing (LARS), which utilizes UAS to acquire Earth surface images at low altitudes, is currently being promoted as a promising alternative platform for RS. To this day, the UAS used for agricultural RS have mostly been low-cost model airplanes with limited payload capability and other sUAS, which have become gradually more accessible to farmers and scientists. These aircraft typically have short flight endurance (less than one hour) and operate at low ground speeds to carry inexpensive multispectral cameras (at typical cost of less than $5,000) to perform LARS at altitudes less than 1,000 ft. over crop fields.

To date, UAS acquired images have been successfully employed in agriculture for detecting small weed patches in rangelands, for documenting water stress in crops, for monitoring crop biomass, for mapping vineyard vigor, for assessing the effects of various nitrogen treatments on crops and for detecting agricultural disease agents. The crop types examined using UAS-collected data include rice, wheat, maize, grapes (in vineyards), and coffee.

As mentioned, spray helicopters have been also employed in RS agricultural missions. In addition, multi-rotor micro UAS mounted with a multispectral camera have been used for weed management and disease detection. Finally, there are some examples of MALE UAS that were used for agricultural RS. NASA’s Pathfinder-Plus UAS can carry two complementary high-definition digital cameras for agricultural surveillance, with one collecting high-resolution color images for qualitative interpretation and mapping of agricultural fields, and the other high-resolution CIR images for quantitative analysis of canopy spectral response to crop ripeness. In 2004, this UAS hovered over specific areas for extended periods at an altitude of approximately 22,000 ft. to provide high-resolution images for analysis of coffee ripeness to determine harvest timing.

Figure 2.10 Imagery Collected by Pathfinder Plus, Coffee Plantation, Hawaii


2.7 Conclusion

This chapter provided background information on UAS in general and in agriculture in particular. It described the historical evolution of UAS, offered classification of civilian UAS, and reviewed the different features of the technology and a subset of key challenges associated with it.

Agricultural missions of UAS fall into one or two categories: delivery/aerial application and RS. Indeed, most uses of agricultural UAS thus far have been of the latter type. As will be discussed elaborately in Chapters 3 and 4, this study seeks to add to the scarce literature on aerial delivery missions in agriculture. Chapter 3 assesses the potential use of UAS to disperse sterilized male flies as part of Sterile Insect Technique (SIT) programs to eradicate Tsetse fly populations. In Chapter 4, the delivery of sound to deter flocks of birds is examined. Because the weight of sound emitters tends to be only a fraction of that of spray systems for example, the technological requirements of UAS to perform sound delivery are much less demanding.

Nevertheless, even though UAS offer abundant opportunities for civilian and commercial uses, in particular in the area of agriculture, integration of this technology into national airspaces will need to address several technical issues in particular communication issues, and non-technical as will be shown in subsequent chapters.
3.1 Introduction

As mentioned in Chapter 2, most research on agricultural UAS missions is concerned with RS and less with delivery/aerial application. This study adds to the agricultural UAS literature by illustrating how this technology may be employed for delivery tasks in farming. In this chapter, I assess the potential role UAS can have in mitigating the detrimental impact to African agriculture borne by the pest Tsetse fly. To do so, the chapter employs Phases 1-3 of the research plan illustrated in Chapter 1 and highlighted in Figure 3.1, i.e., it seeks to characterize an agricultural problem, describe UAS technology offerings, assess whether UAS offer a solution to this problem, and to what extent it offers an improvement over currently-used methods.

Figure 3.1 Research Plan

The chapter utilizes a mixed-method approach. It begins with a literature review to understand the Tsetse problem and currently available means of addressing it. Employing systems-engineering methodology, it subsequently analyzes how UAS specs may fit the requirements of an existing pest management strategy used in Tsetse eradication programs—the sterile insect technique (SIT). Further, it compares the potential benefits and shortcomings of supplanting the manned aircraft currently used in SIT programs with UAS. Finally, it uses a vignette analysis to illustrate how a specific UAS may help quell the Tsetse problem in the context of the Tsetse-infected Niayes region in Senegal.
The remainder of this chapter is organized as follows. Section 3.2 provides background information on the Tsetse fly. Section 3.3 reviews pest management strategies vis-à-vis the Tsetse with a special emphasis on SIT. Section 3.4 briefly presents the methodologies employed in this chapter to assess whether UAS offers a solution to the Tsetse problem, including systems engineering and vignette analysis. Section 3.5 reports the findings from the systems engineering analysis and provides an indication to what extent UAS can meet the requirements of SIT in comparison with manned aircraft. Section 3.6 conducts a vignette analysis to examine this prospect in the local context of North-Western Senegal. Section 3.7 reviews the findings and concludes this chapter.

3.2 Background: The Tsetse Fly

The Tsetse flies are vectors for the single-cell parasite Glossina palpalis gambiensis that causes African animal trypanosomosis (AAT), or ‘nagana,’ one of the most devastating livestock diseases in sub-Saharan Africa. Trypanosomosis leads to a debilitating chronic condition that reduces fertility, weight gain, meat and milk production, and makes livestock too weak to be used for ploughing or transport, which in turn affects crop production.

Tsetse flies infest 37 countries in Africa, covering an area of 5.5–6.5 million square miles, and are estimated to transmit the often-lethal trypanosomiasis to some three million animals clxxxi across the continent each year. Further, approximately 50 million cattle and tens of millions of small ruminants are at risk from the disease. According to the World Health Organization (WHO), 300,000–500,000 people mainly in the rural areas of sub-Saharan Africa are infected by the human African trypanosomiasis (HAT), also known as the African sleeping sickness, and more than 60 million are at risk of the disease clxxxii

Figure 3.2 Cows Suffering from Trypanosomosis, Ethiopia

SOURCE: Fotolia/francovolpato.
The result is immense costs to farmers’ livelihoods and food security. Direct losses in meat production and milk yield and the costs of programs that attempt to control trypanosomiasis are valued at $600 million–$1.2 billion per year. If the lost potential in livestock and crop production is included, trypanosomiasis is estimated to cost sub-Saharan Africa over $4.5 billion each year, equivalent to one-quarter of the area’s total livestock produce. In addition, the loss of human potential is incalculable.

Crop farming and livestock production in sub-Saharan Africa are largely segregated due to the spread of tsetse flies. Some 18 percent of the land area in Africa is humid, which is considers optimal for fodder production. However, only six percent of the continent’s livestock is found in those areas, mostly in scattered pockets of dwarf cattle, sheep and goats, that are resistant to trypanosomiasis. Out of 165 million cattle in sub-Saharan Africa, only 10 million are located in tsetse-infested areas, and the remainder is distributed at the periphery. Figure 3.3 shows the regions where cattle farming is restricted due to the prevalence of the tsetse flies.

3.3 Controlling the Tsetse Fly

Efforts to control tsetse flies began more than 70 year ago. For decades, these primarily chemical measures depended on eliminating wild animals that serve as tsetse hosts, tsetse habitat destruction through clearing bush lands, and extensive insecticide ground spraying. An alternative to the latter, aerosol spraying technique (SAT) has become popular over the last decade as more effective means to deliver insecticides to large areas over a short time. However, continuing environmental contamination, pesticide residues in food and mounting costs of chemicals and personnel have intensified the need for improved pest control and given rise to biological control measures.
Consequently, several safer control measures have been developed and applied including trapping, targeted pesticide treatments and sterile insect technique programs (SIT).

SIT is a form of insect birth control. Mass-bred male flies that have been sterilized by low doses of radiation are systematically released into infested areas, where they mate with wild females—that mate only once in their lifetime—which then do not produce offspring. As a result, the number of flies decreases in the next generation. After multiple iterations leading to a decline in the numbers of flies in subsequent generations, this technique can eventually eliminate populations of wild flies if applied systematically on an area-wide basis.\textsuperscript{cxc} The limitations of SIT are that it is species-specific thus less useful in areas where multiple species are present. In addition, preliminary suppression using conventional methods (killing wild animals that host Tsetse flies, Tsetse habitat destruction, and extensive insecticide ground spraying) is a pre-requisite before SIT can be used. Nevertheless, this limitation is shared across all control measures as only area-wide integrated pest management approaches that integrate both chemical and biological methods, are shown be effective and environmentally-sustainable.\textsuperscript{cxcii} Finally, SIT is labor intensive.\textsuperscript{cxcii} SIT’s advantages on the other hand are that when preceded by other conventional methods, it can provide the final component to an eradication campaign. Additionally, it causes minimal environmental impact, is non-intrusive to other organisms, safe, and effective working in conjunction with other pest control methodologies.\textsuperscript{cxciii}

3.3.1 Sterile Insect Technique (SIT) by Means of Aerial Release

Aerial release in tsetse eradication campaigns refers to either aerial delivery of insecticides in SAT or the discharge of sterile insects from a flying aircraft in the SIT context. Concerning the latter, there are two main categories of aerial release: dropping of a paper bag or cardboard, and chilled insect release. In the bag/box release, the sterile insects emerge within the containers, which are then opened upon release from the aircraft. The main advantage of this method, particularly of the bags, is the low infrastructural or set-up costs. Its disadvantages on the other hand are:

- Labor-intensiveness, due to the need to pack insects into bags/boxes;
- Require a lot of space in the aircraft.
- Less uniform distribution of sterile insects due to intermittent intervals of release;
- Wasteful - as many of the insects never leave the bags/boxes after release; moreover the bags can collapse and damage the insects;\textsuperscript{cxciv}
- Non-environmental—even if made out of biodegradable materials, they still constitute visual pollution and take years to degrade.

The second method, chilled release using an automatic machine, is the most common and preferred approach in biological and integrated insect eradication campaigns and hence is the focus of analysis in this section. Chilled release overcomes most of the drawbacks of the paper bag/box release. Besides being the fastest method of release, it has been demonstrated to provide uniform distribution over target areas and to help ensure sterile insect quality and survivability.\textsuperscript{cxcv} In addition, it enables the release of much higher numbers of sterile insects per trip because of the high concentration of insects and overcoming the packing problems. The disadvantages of this method include the need for a more
sophisticated holding and collection infrastructure and the comparatively expensive equipment required. Notwithstanding these shortcomings, chilled aerial release Aerial release is considered the most cost effective form of SIT especially in medium- and large-scale programs.

At the same time, aerial release is also the most expensive method of release. Its relative cost varies but ranges between 25 and 72 percent of the annual operating budget of sterile fly emergence and release centers—in themselves costly operations relative to conventional eradication methods. This significant cost stems mainly from the over-specification of the aircraft used for SIT aerial release relatively to the requirements of such programs. As outlined below, the requirements of the aerial release stage are far from onerous and the aircraft currently employed in such missions are simply “overkill.” In addition, a major part of currently-used aircraft’s fuel consumption is takeoff weight, a significant share of which (between 30 and 60 percent) is the crew onboard. Eliminating the need for on-board crew can contribute toward cost-savings in aerial release of sterile flies in SIT programs. Given the centrality of this method to pest management efforts, any cost savings in this area can be meaningful, especially in poor areas such as sub-Saharan Africa.

Tan’s and Tan’s study, which surveyed alternative forms of aerial transport, found that UAVs have the potential to meet key specifications of SIT chilled aerial release requirements in a costly-effective manner. The following analysis expands upon their efforts and refines the results by focusing on how UAS meet aerial release requirements and how they compare to manned aircraft on several parameters including flight range, altitude, release accuracy, weight, environmental issues, and costs. Moreover, the vignette in Senegal supports the analysis in a local sub-Saharan Africa context.

3.4 Methods

Following background research and literature review on the Tsetse problem and currently-used methods to address it, the study seeks to understand whether UAS can be used in aerial release programs. To do so, the chapter employs a system’s engineering methodology. According to the International Council on Systems Engineering (INCOSE), systems engineering is an interdisciplinary approach that focuses on “defining needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem . . . with the goal of providing a quality product that meets the user needs.”

In the context of the Tsetse challenge, assessing to what extent UAS can potentially be employed in aerial chilled release programs and supplant manned aircraft as aerial release vehicles, hinges on understanding the characteristics of the chilled aerial release programs, and assessing how well UAS can fulfill these requirements relatively to manned aircraft.

To date only very few pilot programs have begun testing suppression of tsetse fly populations by SIT areal release. Thus, data is still insufficient for comparative analysis between manned aircraft and UAS.
Therefore, most parameters are derived from equivalent programs to eradicate fruit fly populations, which are quite common both in the United States and in Latin America. The scarce data on chilled release of sterile tsetse flies is utilized in defining the payload of the insects, altitude of their release and so forth as well as in the vignette.

The aircraft employed in most fruit fly SIT programs using aerial release are either fixed-wing aircraft or helicopters when the terrain is mountainous. Aircraft in smaller- and medium-scale programs include for example Cessna 172, 206, 207, 208; Beechcraft King Air 90; Piper PA-28; Helicopter Bell 206, 212; and Gyrocopters. In larger programs, much larger aircraft with payload capacity of over 2,200 lb. are used including the Turbo-Let 410, and Cessna 401 and 402-twin engine.\textsuperscript{cciv}

In assessing whether, and to what extent, UAS have added value over such manned aircraft in aerial release missions, the comparison focuses on factors including flight range, release airspeed, altitude, weight, safety, environmental issue, costs, and others as outlined below.

In addition, this chapter includes a vignette analysis in which the hypothetical use of UAS in an aerial chilled release program in Senegal is examined. Fitting the analysis in a more specific geographical and political context has helped illuminate some of the challenges and opportunities associated with his prospect.

3.5 Findings: To What Extent Can UAS Meet Aerial Chilled Release Requirements?

This section outlines all of the requirements of aerial chilled release and subsequently assesses if, and how, UAS are able to fulfill these requirements. The results of this assessment indicate to what extent UAS is compatible for aerial chilled release programs, and the relative performance of this technology in comparison to the manned aircraft currently used in similar missions. These findings are reported by type of requirement, and are summarized in Table 3.3.

**Weight**

Weight is a general parameter that encompasses three dimensions: the payload, the operating weight, and the weight of the aircraft—all important factors that determine airplane capabilities. Payload in the context of SIT programs employing aerial release includes the insect payload and the release machine. The aircrew onboard is considered part of the operating empty weight, and the gear that supports the aircrew is part of the weight of the airplane itself, as explained below.

- **Insect payload:** Most small- and medium-scale fruit fly SIT programs sponsored by the United States Department of Agriculture (USDA) release three to eight million flies per flight.\textsuperscript{ccv} Each fly weighs about 0.000211 oz. (6 milligrams), thus the insect payload of eight million sterile flies is around 105 lb. Tsetse eradication programs however require much smaller numbers of sterile flies at a rate of 50 flies per squared kilometer which is 200 times lower than for fruit flies. Thus, for the sake of this analysis an insect payload of 0.5–1 lb. will be used in all calculations.
- **Release machine**: The Mubarqui Smart Release Machine (MSRM2), which is suitable for release of Tsetse flies, weighs 140 lb., and does not take up much space on aircraft.\textsuperscript{ccvi}

- **Crew onboard**: depending on the aircraft, either one or two crew members can be on board. Assuming an average weight of 180 lb. per person, the addition to the empty operating weight as a result of onboard crew is 180–360 lb.

- Crew accommodation equipment is estimated at 70–210 lb.\textsuperscript{ccvii} (depending whether one or two members are on board), and is included in the weight of the aircraft—one of the parameters that make the currently employed airplanes over-specified for this type of mission. SIT programs vary in scale and the weight fraction that is the air crew’s weight changes accordingly.

In summary, assuming a small–medium scale program with 0.5–1 lb. insect payload and 140 lb. release machine, the payload capacity to eradicate the fly population is 141 lb. When there is a need to accommodate air crew that weighs 180–360 lb., the aircraft should be able to carry heavier weight and be large enough to accommodate the crew with gear that weighs 70–140 lb. Such airplanes are normally significantly over-specified for this mission. For example, a large fruit fly program in Mexico releases 60 million flies per flight which makes 927 lb. payload uses the relatively large Cessna 402s, the payload capacity of which exceeds the requirement by over 2,000 lb.

Table 3.1 lists examples of aircraft used in aerial release of SIT programs, their payload specifications in comparison to required payload, and weight capacities. These figures are derived from corresponding insect payload, and an average weight of 140 lb. for the release machine. In general, it is clear that most aircraft currently used are underutilized, being heavy airplanes with payload capacity of over 1,100 lb.

Various classes of UAS can carry a 141 lb. payload. The average payload of Vertical Take-Off and Landing (VTOL) UAS is 180 lb.\textsuperscript{ccviii} Other classes including Low Altitude Low Endurance (LALE), and Medium Altitude Medium Endurance (MALE) can carry larger payloads. Yet, VTOLs are often preferable for aerial release missions for their maneuverability and vertical takeoff capability, obviating the need for runway.
Table 3.1 Selected Aircraft for Chilled Aerial Release

<table>
<thead>
<tr>
<th>Fly Specie</th>
<th>Flies/Load</th>
<th>Aircraft</th>
<th>Air Crew</th>
<th>Payload Capacity</th>
<th>Required Weight</th>
<th>Price $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medfly</td>
<td>40 million</td>
<td>Cessna 402</td>
<td>1</td>
<td>2,781 lb.</td>
<td>665 lb.</td>
<td>&gt;1m²</td>
</tr>
<tr>
<td>Medfly</td>
<td>5 million</td>
<td>Beechcraft</td>
<td>1</td>
<td>1,504 lb.</td>
<td>205 lb.</td>
<td>1.1m</td>
</tr>
<tr>
<td>Mexfly</td>
<td>5 million</td>
<td>Cessna 206</td>
<td>1</td>
<td>1,373 lb.</td>
<td>205 lb.</td>
<td>500k</td>
</tr>
<tr>
<td>Medfly</td>
<td>18 million</td>
<td>Bell 206</td>
<td>1</td>
<td>2,123 lb.</td>
<td>376 lb.</td>
<td>1.7m</td>
</tr>
<tr>
<td>Tsetse</td>
<td>15,000</td>
<td>Gyrocopter M24</td>
<td>1–2</td>
<td>1,100 lb.</td>
<td>141 lb.</td>
<td>133k</td>
</tr>
</tbody>
</table>

Adapted from FAO using various open internet sources of aircraft manufacturers

Environmental Burden

The weight of the air crew and the accommodating gear does not only affect the size of the airplane. Considering the fact that takeoff and landing account for the majority of the total fuel consumption in flights, reducing the takeoff and landing weight is the key to decreasing fuel consumption and minimizing cost, both financial and environmental. Current SIT aerial release vehicles, however, have relatively high air pollution resulting from high fuel consumption, as well as noise pollution characteristics. Obviating the need for a pilot onboard will lower fuel consumption and in turn environmental burden.

Cost

Relatively to other forms of release, aerial release in SIT programs is significantly more expensive. Thus, any cost savings in this stage can be important for integrated eradication campaigns that consider aerial release as part of a SIT approach. These costs can be broken down into two types: fixed and operational costs.

Fixed Costs

The fixed costs associated with purchase of the aircraft currently used in SIT programs range from $133,000 (the gyrocopter) to $1.7 million, as shown in Table 3.2. Thus, aerial release is frequently contracted out to specialized services that provide the aircraft, operational and pilot fees. The hourly rate for such contracts is $465 for some 35 hours per week. The scale of such contracts can be derived from the example of the Sarasota SIT facility in Florida, which conducted 35 hours per week of aerial releases in 2002 leading to a contract of $846,000 that year.

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3 Medfly refers to the Mediterranean Fruit Fly or in its scientific name Ceratitis capitata;
4 The Cessna 402 is out of production. Smaller models of Cessna cost around $1 million.
5 Mexfly is the Mexican Fruit Fly, and its scientist name Anastrepha ludens.
The fixed costs associated with UAS are relatively high as well ranging from $10,000 to a few millions. The prices of VTOLs range from $25,000 to $350,000 per vehicle, amounting to $250,000–$1 million for a full system that includes ground control station and the other elements.\textsuperscript{ccxi} Some of the popular RMAX models for agriculture range between $86,000 and $230,000.\textsuperscript{ccxii} It is estimated that most UAS that fulfill SIT aerial release needs cost over $1 million. Nevertheless, numerous research projects are seeking to develop lower cost UAS for civilian applications.\textsuperscript{ccxiii} Other fixed costs may be associated, if need, with paving a runway and building a hanger.

### Operational Costs

These include fuel, wages for air and ground crews, hanger rental, airport and runway charges (if applicable), and maintenance costs. Operational costs depend on the type of aircraft. For example, fixed-wing require a runway for taking off and landing, thus necessitate either runway rental, or the availability of land and investment in infrastructure to build a runway. Moreover, depending on weather, the aircraft may need to be housed in a hanger when not uses requiring hanger rental.

The costs of such long-term investments, as well as wages, depend primarily on local economic conditions as the price of land, rental fees and labor, which vary significantly between countries and continents. Similarly, depending on the air vehicle, maintenance checks are required before and after each flight and they must be in accordance with regulations by the country’s aviation authority, again accounting for a variety of maintenance costs. Nevertheless, such costs cannot be underestimated.

To provide some context on the magnitude of operational costs, in 2007, the total aerial release costs of eight fruit fly emergence and release facilities was $10.1 million out of a total operating budget of $24.3 million—42 percent of the operating budget of these facilities.\textsuperscript{ccxv} Therefore, eliminating the need for air crew, runway (if helicopters, manned or unmanned, can be used), lowering fuel consumption, and other maintenance fees can contribute meaningfully toward cost-savings in SIT programs.

In comparing UAS to manned aircraft currently employed for aerial release in SIT programs, it is useful to breakdown operational costs to the following specific components. The costs associated with hanger
rental and runway fees are excluded from this comparison because both manned aircraft and UAS may require those.

- **Fuel consumption**: manned aircraft consume on average 20 gallons per hour (GPH), as shown in Table 3.2 versus around 5 GPH for UAS.
- **Wages**: unlike manned aircraft that necessitate a pilot and often another crew member onboard, UAS do not require air crew. The capabilities and risk to pilots in the air are greater and different than UAS pilots/operators. Ground crew is required for takeoff and landing, communication and maintenance. Civilian UAS require at least two ground crew members to fly, search and monitor the aircraft.
- **Maintenance costs**: in the military realm, these costs are relatively high for both manned and unmanned aircraft due to safety regulations. However, there is more variation in civilian UAS, from commercial off-the-shelf (COTS) to more sophisticated platforms. The safety requirements may be as stringent as military counterparts or more permissive in the case of sUAS (less than 55 lb.) flying during daylight and at an altitude of up to 500 ft.

**Release Airspeed**

Airspeed during release varies according to program, region, release machine, and so forth. Nevertheless, the airspeed should ensure optimal release of sufficient quantities of functional sterile flies where they are needed. Low airspeed jeopardizes the insect quality because they are being held in low temperatures for a long time. Higher airspeed on the other hand shortens flight range and increases fuel consumption. Considering pros and cons, the FAO/IAEA notes a 90 miles/h average speed for chilled adult release in fruit fly programs. In Tsetse pilot programs, the average speed was 70 miles/h. Suitable UAS fly at a speed around 70–125 miles/h. Spacing of release also varies by program. In most chilled fruit fly programs in the USA the lane spacing is 880 ft. In preventive release programs covering flat terrains, 1,760 ft. spacing is used between lanes. In Mexico on the other hand a shorter distance between lanes of 320 ft. is used to ensure total coverage of the infested area.

**Altitude**

Many factors need to be considered in determining the altitude of releases including wind, temperature, cloud cover, fog, smog, terrain and others. The altitude at which the aircraft flies is not only important for release accuracy but also for the functionality of the sterile insects. Those insects are kept immobile in boxes under low temperatures, and warm up upon release and descent. The calculation of suitable altitude has to ensure that insects gain normal activity by the time they arrive near the ground. This calculation varies by region and climate, but in general—where air temperatures are higher, the release altitude for release is lower. For example, the altitude used in the USA is 2,000–2,500 ft. above ground level (AGL), and flies are usually not released lower than 492 ft. to avoid some of them reaching the ground before warming up. The downside of higher altitudes is excessive drift of flies. In Mexico, in warmer areas with flat terrain, flies are released at 328 ft. AGL, an altitude that allows for their activation by the time they reach ground. Similar altitude was used in Tsetse pilot programs in Africa.
**Flight Range**

Aerial release of sterile male flies should cover regions in full to both ensure fly population suppression as well as prevent relocation of unmated female flies to adjacent areas. The size of the areas normally covered in fruit fly programs is around 100 square miles per flight. Currently used aircraft have a range of around 190 miles. Smaller UAS have a theoretical flight range of 100 miles and medium-size UAS reach up to 1,000 miles. This however does not consider the LOS communications range, which as explained in Chapter 2, and shown again in Table 3.3, MAV UAS operating at an altitude of 100 ft. (328 meters) are limited in LOS communication range to 5.78 km, or 3.6 miles. A UAS of VTOL class is limited to 80 km in communications range (49.7 miles). Indeed, while this communications challenge may be mitigated by some of the options reviewed in Chapter 2 (accommodating this challenge by dividing the range and covering only smaller parts of it at a time; miniaturization and cost reduction of SATCOM; the use of cellular networks; and autonomous operation when UAS beyond LOS), this challenge may be a determining factor in choosing the right UAS class for this mission. Clearly, this provides another reason, in addition to the payload weight requirement, why small UAS are unlikely candidates for chilled aerial release.

<table>
<thead>
<tr>
<th>Aircraft Altitude (km)</th>
<th>Max Operating Range (km)</th>
<th>Civilian UAS Class</th>
<th>Class Max Altitude (km)</th>
<th>Class Max Range (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>5.78</td>
<td>MAV/NAV</td>
<td>0.30</td>
<td>5.78</td>
</tr>
<tr>
<td>0.50</td>
<td>9.44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>18.68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>36.64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.05</td>
<td>54.77</td>
<td>LASE</td>
<td>3.05</td>
<td>54.77</td>
</tr>
<tr>
<td>3.72</td>
<td>66.03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.00</td>
<td>70.67</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.57</td>
<td>80.01</td>
<td>VTOL, LALE</td>
<td>4.57</td>
<td>80.01</td>
</tr>
<tr>
<td>5.00</td>
<td>86.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.00</td>
<td>102.58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.00</td>
<td>132.71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>161.34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.19</td>
<td>191.28</td>
<td>MALE</td>
<td>12.19</td>
<td>191.28</td>
</tr>
<tr>
<td>14.00</td>
<td>214.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.00</td>
<td>240.04</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>18.00</td>
<td>264.32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21.34</td>
<td>303.10</td>
<td>HALE</td>
<td>21.34</td>
<td>303.10</td>
</tr>
</tbody>
</table>
**Release Accuracy**

Sterile insects need to be released along predetermined equally spaced release paths to ensure their uniform distribution as well as full coverage of the target area. Therefore, the aircraft needs to be able to fly accurately along release paths, and to record adherence to these paths using GPS and other associated software to monitor area coverage and swath distance. UAS and manned aircraft both have high safety standards as they operate on GPS-based control systems. The release machines themselves are equipped with a navigation system that guides the pilot to the release areas (presented as polygons). This system also contains the logging, measurement and automation of the release. Finally, the machine has video cameras for confirmation that the flies are indeed being released. One challenge may be in adapting the release machines designed for manned aircraft to UAS.

While reliable, automated or semi-automated release of cargo over pre-defined GPS coordinates remains a non-trivial task, the required accuracy in chilled aerial release programs is not very high because full areas are covered. Thus, a GPS solution should be sufficient even if the release is slightly off.

**Ground Facility Requirements**

Ground facilities requirements, which make up a portion of the operational costs, vary with aircraft type. For example, fixed-wing aircraft, in similar to most classes of UAS, require air traffic control, hanger space and a runway. In contrast, helicopters and VTOLs obviate the need for a runway, both in manned as well as unmanned systems. Thus, any comparison in this area between manned aircraft and UAS should be case-specific, as will be illustrated in the subsequent vignette.

**Safety**

Chilled aerial releases have high standards to ensure the safety of the crew, to protect the costly aircraft and release machines, and to avoid third party damage in an event of aircraft failure. UAS have a relatively high rate of mishap compared with fixed wing aircraft. However, this rate is declining similarly to that of manned aircraft hence major improvements in safety are anticipated. Moreover, UAS failure does not lead to loss of life, i.e., aircrew is out of harm’s way, and are therefore considered safer. At the same time, UAS can cause third party damage if they crash. Indeed, UAS mishap rates are high but are declining at a rate similar to that of manned aircraft.

**Weather Conditions**

Notwithstanding advances in technology that allow aircraft—manned and unmanned—to fly in various weather conditions, such capabilities are not required for aerial release in SIT programs because sterile insects are released only when conditions are best for their survival, performance and delivery to the right spots.

**Conclusion**

As summarized in Table 3.4, UAS comply with most of the requirements of SIT programs and can supplant manned aircraft in aerial release. As demonstrated, they may not only be more cost effective
but also provide added value in terms of environmental damage and safety. The stoplight chart colors help illustrate how well UAS fulfill the chilled aerial release needs in comparison to manned aircraft. The bright green color denotes excellent match and improvement; the lighter green also indicates a fine fit and upgrading; yellow indicates average quality match and marginal improvement over manned aircraft. Red, not included would have signaled mismatch.

### Table 3.4 How UAS Specs Match Aerial Chilled Release Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>UAS Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Payload Weight:</strong></td>
<td>High. The average payload of VTOL UAS is 180 lb. LALE and MALE classes can carry even larger payloads. Manned aircraft can carry such payload but need to accommodate 1–2 crew members and supporting gear resulting in over-sophisticated aircraft for this mission.</td>
</tr>
<tr>
<td><strong>Environmental Burden:</strong></td>
<td>High. Lower weight of UAS leads to lower fuel consumption and results in lower air pollution. Noise emission is similar in UAS, manned aircraft.</td>
</tr>
<tr>
<td><strong>Fixed Costs:</strong></td>
<td>Medium. VTOLs price range is $25,000–$350,000 per vehicle, amounting to $250,000–$1 million for a full system. Some of the popular RMAX models for agriculture range between $86,000 and $230,000</td>
</tr>
<tr>
<td><strong>Operational Costs:</strong></td>
<td>Medium. Fuel consumption in UAS is around 5 g/h. UAS and manned aircraft share the needs for ground crew but whereas for manned aircraft usually 3 ground crew members are present, with UAS, 1–2 members are needed for search and execution of mission. Both aircraft require air traffic control, and mandatory maintenance checkups to comply with safety regulations.</td>
</tr>
<tr>
<td><strong>Flight Range:</strong></td>
<td>Medium-low. LOS communications range (and the requirement to fly at 328 ft.) may limit certain types of UAS from performing this mission.</td>
</tr>
<tr>
<td><strong>Altitude:</strong></td>
<td>High. UAS fly at altitudes ranging from 50 to 60,000 ft., with relevant classes (mini, VTOL, and LASE) flying at a maximum altitude of 15,000 ft.</td>
</tr>
<tr>
<td><strong>Ground Facility Requirements:</strong></td>
<td>Medium. UAS require facilities similar to manned aircraft; however depending on design may not need runways and large hangars. As mentioned under Operational Costs, UAS may be more economical in terms of ground crew members.</td>
</tr>
<tr>
<td><strong>Safety:</strong></td>
<td>High. UAS mishap rates high but declining at rate similar to manned aircraft. Pilot out of harm’s way.</td>
</tr>
<tr>
<td><strong>Release Airspeed:</strong></td>
<td>High. Suitable UAS fly at a speed around 70–125 miles/hour.</td>
</tr>
<tr>
<td><strong>Weather Conditions:</strong></td>
<td>High. UAS can operate under such benign weather conditions.</td>
</tr>
<tr>
<td><strong>Release Accuracy:</strong></td>
<td>High. UAS and manned aircraft both have high safety standards as they operate on GPS-based control systems, which are sufficient for non-strict accuracy requirements of the programs.</td>
</tr>
</tbody>
</table>

Referencing: 

- xxiv
- xxv
- xxvi

45
3.6 Vignette Analysis: Could UAS Help Eradicate Tsetse Flies in Niayes, Senegal?

3.6.1 Background
The Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture is currently supporting 14 African countries in integrating SIT aerial release with other more conventional control methods of the tsetse flies. One of the program’s central foci is the Niayes area in Senegal. The following vignette illustrates how UAS may supplant the manned aircraft currently employed in the Niayes region. In addition to addressing the SIT requirements described above, this vignette elaborates the analysis and discusses program specific considerations including target area, polygon shape and size, geographical situation, pest situation, and others.

3.6.2 Why Niayes, Senegal?
The Niayes area of Senegal was selected for this vignette for several reasons, including its geography, demography, and role of agriculture in its economy, food security status, and others. Located north-east of Dakar, the Niayes region marks the north-western boundary of the tsetse fly distribution in Africa. The maps in Figure 3.4 show Niayes is located in Senegal as well as in the larger Africa context.

![Figure 3.4 The Location of Niayes Area in Senegal and the Large Africa Context](image)

The Senegalese population has increased tenfold in the last century to 14.55 million in 2014, and is expected to triple by 2050. The highly dense Niayes, an area of around 386 square miles, contains 53 percent of the country’s population, with over 388 people per square mile.
Senegal is poor country that relies heavily on donor assistance and foreign direct investment. Its economy is characterized by weak infrastructure, challenging business environment, and a culture of overspending. In recent years, the country has suffered from unreliable power supplies and rising costs of living, which has led to public protests and high unemployment.\textsuperscript{ccxxx} Table 3.5 provides background statistics on Senegal’s economy.

\textbf{Table 3.5 Senegal’s Economy: Background Basics}

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value</th>
<th>Country Rank Worldwide</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>$27.72</td>
<td>120</td>
</tr>
<tr>
<td>GDP per Capita</td>
<td>$2,100</td>
<td>193</td>
</tr>
<tr>
<td>Labor force</td>
<td>6.096 million</td>
<td>67</td>
</tr>
<tr>
<td>Labor Force in Agriculture</td>
<td>77.5%</td>
<td>N/A</td>
</tr>
<tr>
<td>Unemployment Rate</td>
<td>48% (2007)*</td>
<td>195</td>
</tr>
<tr>
<td>Population below Poverty Line</td>
<td>54% (2001)*</td>
<td>N/A</td>
</tr>
<tr>
<td>External Debt</td>
<td>$4.375 billion</td>
<td>125</td>
</tr>
</tbody>
</table>

Adapted from the CIA’s Factbook (2013)

* Data is missing for these indicators for later years however it is estimated that both unemployment rate and the share of population under the poverty line have worsened in recent years as a result of the global recession, climate change and political instability.

Agriculture is the driver of Senegal’s economy and the sector is the primary source of employment in the rural areas. The dependency on agriculture makes the Niayes region indispensable for the country’s economic development. Niayes has a coastal micro-climate favorable to agriculture in general and animal production in particular. Primarily, it is suitable for exotic cattle breeds uniquely apt for milk and meat production. Nevertheless, the Niayes is also favorable to the Tsetse fly. As a result, most domestic animals in the area—especially exotic cattle—are susceptible to AAT. On average, more than 30 percent of cattle population in the area has been historically infested.\textsuperscript{ccxxi}

The infestation of the Niayes region with Tsetse flies has adverse consequences for Senegal’s food security status. As a result of population growth and changing diets, the demand for milk has increased substantially in last decades, and is projected to rise by 52 percent over 10 year.\textsuperscript{ccxxii} Milk supply has never caught up though. Despite tremendous genetic potential of exotic cattle breeds, optimal climate conditions, substantial use of farming inputs, and wide government support, mean daily milk production has remained very limited.\textsuperscript{ccxxiii} Moreover, reliance on milk imports has proven insufficient to meet national demand for milk.\textsuperscript{ccxxiv} Thus, Senegal and the international community have signaled out investment in the Niayes’ cattle as a plausible solution to this national nutritional challenge.

Furthermore, the Tsetse flies hinder economic development of the Niayes. A study commissioned by Senegal’s Government in 2005 estimated the opportunity costs for the region’s farmers associated with the Tsetse at $1.6 million per year.\textsuperscript{ccxxv} Specifically, the study found that farmers located outside the
Tsetse infested area of Niayes produced 38 percent more milk, 64 percent more meat, and sold 2.8 times more livestock than those located in the area for similar herd sizes. Another study projected a threefold increase in cattle sales (milk and meat) as a result of the removal of the G.p. gambiensis.

The cumulative disastrous impact of the Tsetse infestation the Niayes region created ample political will for addressing this problem. In 2006, backed by strong public support and financial resources, the Senegalese government joined the Pan African Tsetse and Trypanosomosis Eradication Campaign (PATTEC), which was launched five years earlier by the African Union, and committed to creating a sustainable tsetse free zone in the Niayes.

To support Senegal, many partners have joined this endeavor. For example, the Senegal Institute for Agricultural Research (ISRA) has been collaborating with the Directorate of Veterinary Services (DSV) of the Ministry of Livestock in the implementation of a tsetse suppression effort since 2006.

In addition, the government receives technical and financial support from the Joint FAO/IAEA Program of Nuclear Techniques in Food and Agriculture and its Department of Technical Cooperation, the United States (through its Peaceful Uses Initiative (PUI)), and France (through the deployment of a CIRAD staff member on site in Senegal).

3.6.3 Is Chilled Release Feasible in the Niayes?

As explained in Section 3.3 Suppressing and Eradicating Tsetse Fly Populations, SIT is a biological control method that unlike conventional chemical measures is effective, safe and environmentally-sound. However, SIT has several limitations, the primary of which are its species-specific nature and the prerequisite to employ other techniques in preliminary suppression efforts. Thus, prior to analyzing the prospects of chilled aerial release using UAS, it is imperative to examine the general feasibility of employing the SIT method in the Niayes region.

Biological & Environmental Feasibility

Between 2006 and 2010, Senegal conducted several studies that analyzed the Tsetse habitat. These studies found that the Tsetse habitat was fragmented (not contiguous), that flies were present in very small pockets but at high densities, and that the total infested area was limited to 325 square miles. Moreover, a fly genetic survey revealed that the only Tsetse species in the Niayes is the Glossina palpalis gambiensis, and that this population is genetically different from the nearest concentration of Tsetse population in the region known as the “main tsetse belt” of Senegal. The study concluded that the isolation of this fly population could enable the production of sterile males in a laboratory, and that it safeguards against the risk that Tsetse flies from other areas will reinvade the Niayes region.

Moreover, the SIT program was designed to follow a suppression phase utilizing more conventional methods (e.g., elimination of Tsetse host animals, ground spraying). This phase was extremely efficient, leading to 90–99 percent reduction in fly population density, however was followed by a leveling-off of
the fly density. Based on a similar experience in Guinea, it was estimated at the time that only SIT would lead to complete elimination of the Tsetse flies.\textsuperscript{ccxi}

Finally, an environmental study to assess the possible effects of Tsetse eradication efforts’ on biodiversity and the ecosystem found that thus far there has been no significant impact has been measured.

Weather Feasibility
As indicated above, sterile insects are dispersed only when conditions are optimal for their quality, survival, and accurate release. Thus, rather than a characteristics of the chilled aerial release requirement, weather can be considered as part of the feasibility analysis—aerial release is operational if and only if meteorological conditions permit it.

In Senegal, there are two main seasons: the rainy season (July to October) and the dry season, subdivided into the cold dry season (November to February) and the hot dry season (March to June). In the Niayes region, the average monthly temperature in July/August fluctuates around 81.5°F. From November to February, the maximum temperature is below 82.4°F while the minimum temperature is 64.4°F. Moderate Harmattan wind\textsuperscript{6} can increase temperatures up to 87.8°F in May and June. Rainfall in the Niayes rarely exceeds 350 mm/year.\textsuperscript{ccxiii} Infrequently, extreme winds, rain or temperature may not be suitable for the chilled release action. Examination of historical weather patterns suggests that during the rainy months of August–September (and to lesser degree, July and October), aerial release may not be executable six days of each month on average.

Political and Financial Feasibility
The combination of political backing and financial resources donated for this goal by the international community have enabled Senegal to launch an area-wide integrated pest management (AW-IPM) campaign that included conventional and non-conventional methods, and thus address the second shortcoming of SIT—the precondition of initial suppression of the fly population utilizing other means. The availability of resources have also allowed Senegal to opt for chilled aerial release over the less-preferred but also less costly box/bag drop method.\textsuperscript{ccxiv}

The first stages of the suppression campaign included several strategies, the key of which are application of insecticide as pour-on on livestock and placement of traps and nets. In preparation for the chilled aerial release technique, a species-specific strain of sterile male flies was developed; a dispersal center in Dakar was established; ground trial releases were conducted to assess the performance of the sterile

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\textsuperscript{6} The Harmattan is a dry and dusty West African trade wind. This northeasterly wind blows from the Sahara into the Gulf of Guinea between the end of November and the middle of March. In extreme cases, this wind can bring about heavy dust which limits visibility. Under such circumstances, flights are restricted. However, the selection of Niayes for the eradication project employing aerial release suggests that the Harmattan wind in the area is moderate.
flies in the area (in meeting criteria such as competitiveness with native males, survival, and effective dispersal); and data of temporal and spatial dynamics of the native fly population were collected. Finally, aerial trials using a Mubarqui Smart Release Machine (MSRM2) mounted on a gyrocopter MAGNI M16, by MAGNI Gyro, proved successful. The formal aerial phase is now in initial stages.\textsuperscript{ccxlv}

**Figure 3.5 MSRM2 Mounted on Magni Gyrocopter, Trial in Niayes, Senegal, February 2014**

![Image of MSRM2 mounted on a gyrocopter](source)

SOURCE: FAO/IAEA’s project against the tsetse fly in the Niayes.

While the gyrocopter has certain advantages; eliminating the need for on-board crew can contribute toward important cost-savings in the release stage, a pertinent factor for a poor country like Senegal, the economy of which depends on agricultural development.\textsuperscript{ccxlv} As the following analysis demonstrates, the requirements of the aerial phase in the Niayes region can be fulfilled by UAS, which not only can be more cost-effective but also safer and environmental-friendlier.

### 3.6.4 How Could UAS Meet the Chilled Aerial Release Needs in the Niayes?

To assess whether, and to what extent, UAS can meet the requirements of the chilled aerial release plan in the Niayes region in Senegal, this analysis follows the system engineering approach developed earlier to examine to what extent the technology offerings fulfills the requirements posed by the problem.

To add context to the discussion, this assessment considers the characteristics of a certain UA in mind—the Ag-210, a VTOL aircraft manufactured by AgAiRobot Inc. VTOLs in general are advantageous in situations when terrain is limited or when hovering capability is required. Moreover, their ease of maneuverability makes them more suitable to navigate through at low altitude than can fix aircraft.\textsuperscript{ccxlv} It is important to note that this analysis by no means advocates the use of Ag-210. However, it was selected as an example of an unmanned helicopter after an open-source survey of commercial off-the-shelf unmanned VTOLs found it to be potentially capable of fulfilling the core requirements of the aerial release stage. In addition, it is comparable to the gyrocopter currently used in the pilot SIT program in Senegal. Table 3.6 outlines the basic characteristics of the Ag-210 and its performance specs.
Table 3.6 Characteristics of Ag-210

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>149 in.</td>
</tr>
<tr>
<td>Rotor Diameter</td>
<td>168 in.</td>
</tr>
<tr>
<td>Gross Weight</td>
<td>463 lb.</td>
</tr>
<tr>
<td>Payload Capacity</td>
<td>176 lb.</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>4.5 GPH</td>
</tr>
<tr>
<td>Fuel Type</td>
<td>Fuel mixed with oil (50:1)</td>
</tr>
<tr>
<td>Engine Type</td>
<td>Hirth-F23 ES TBO 1,000 hours</td>
</tr>
<tr>
<td>Power</td>
<td>50hp at 6,150rpm</td>
</tr>
<tr>
<td>Data Link</td>
<td>N/A</td>
</tr>
<tr>
<td>Frequency</td>
<td>N/A</td>
</tr>
<tr>
<td>Endurance</td>
<td>N/A</td>
</tr>
<tr>
<td>Max speed</td>
<td>98mph</td>
</tr>
<tr>
<td>Ceiling</td>
<td>N/A</td>
</tr>
<tr>
<td>Range</td>
<td>150m (Visual Observation Range) GPS Optional</td>
</tr>
<tr>
<td>Takeoff Means</td>
<td>Vertical</td>
</tr>
<tr>
<td>Landing Means</td>
<td>Hover</td>
</tr>
</tbody>
</table>

SOURCE: AgAiRobot Inc

Weight

The payload capacity required to release the sterile tsetse flies in the Niayes, as in other SIT programs, is one that would suitable for the release machine and the sterile insects themselves.

Insect Payload

The capacity of the MSRM2 machine used in this program is 15,000 flies, each weighing 21 milligram, or 0.0111 oz.\(^{ccxlvi}\) Assuming full capacity is utilized, 15,000 flies weigh 0.7 lb.

Release Machine

The MSRM2 weighs 140 lb.\(^{ccxlix}\)

The MSRM2 is designed according to the manufacturer to maximize the accuracy of the release rate of the sterile flies. The release rate of flies is controlled by several variables that are operated by a digital controller and a program adapted to the project’s needs, in this case—the calibration of flies per hectare. The machine self-calibrates during the flight without intervention of a pilot or operator. The objective of this automation of the MSRM2 was designed to minimize human error. However, in the context of this study it serves as an indication for the potential obviation of aircrew in such missions.
UAS Potential Fit
The 2-man gyrocopter employed in the Niayes trial has payload capacity of 1,100 lb. The crew onboard accounts for 360 lb. and crew accommodation equipment is at 210 lb.\textsuperscript{ccl} Different classes and types of UAS can meet the payload requirement of 140.7 lb. but because a helicopter is being used in the Niayes, it is more reasonable to compare its performance to that of unmanned VTOLs. On average, unmanned VTOLs have payload capacity of 180\textsuperscript{ccl}—sufficient to carry the machine and sterile insects. An example of such a VTOL is Ag-210, an unmanned helicopter developed for agriculture by AgAiRobot Inc., which has payload capacity of 176 lb.\textsuperscript{ccl}

Environmental Burden
The MAGNI M16 gyrocopter used in the trial in the Niayes has relatively low fuel consumption of 6 GPH, even relatively to unmanned VTOL which on average have fuel consumption of 5 GPH. Nevertheless, the major component of fuel consumption in the majority of aircraft is the take-off weight. In the Niayes program, the weight of the release machine and the insects is only 140.7 lb. whereas the weight of two aircrew members and accommodating gear is 570 lb., 80 percent of the total load.

UAS Potential Fit
Eliminating the need for onboard crew, and by that reducing the takeoff weight, would contribute toward lower fuel consumption and as a result, would lower air pollution.

Cost

Fixed Costs
The fixed costs associated with purchase of the gyrocopter currently used in the Niayes starts at $133,000 for the vehicle itself. The fixed costs associated with UAS are relatively high as well. The prices of VTOLs range from $25,000 to $350,000 per vehicle.\textsuperscript{ccl} The Ag-210 for example is $180,000.\textsuperscript{ccl} In the case of employing helicopters, manned or unmanned, there is no fixed cost associated with paving a runway. Expenses related to building—or renting—a hanger will differ depending on size. The Gyrocopter is larger in size than the Ag-210 for example thus will require larger hanger (Table 3.7) which may be more costly.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Gyrocopter</th>
<th>Ag-210</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor Diameter</td>
<td>28 ft.</td>
<td>14 ft.</td>
</tr>
<tr>
<td>Height</td>
<td>103 in.</td>
<td>60 in.</td>
</tr>
<tr>
<td>Length</td>
<td>184 in.</td>
<td>149 in.</td>
</tr>
<tr>
<td>Empty Weight</td>
<td>595 lb.</td>
<td>230 lb.</td>
</tr>
</tbody>
</table>

SOURCES: Magni Gyro; AgAiRobot Inc.
Operational Costs

As discussed earlier, operation costs include fuel, wages for air and ground crews, hanger rental, airport and runway charges (if applicable), and maintenance costs. In assessing the potential fit of UAS to the Niayes in Senegal, and comparing them against the currently-used Gyrocopter, I expand on the aforementioned breakdown of costs to include training, but exclude costs associated with hanger rental for lack of data on rental fees in the area.

Fuel Consumption

While the MAGNI M16 gyrocopter used has relatively low fuel consumption of 6 GPH, unmanned VTOLs on average have fuel consumption of 5 GPH. Moreover, considering that take-off weight accounts for the factor most affecting fuel consumption during takeoff and landing, any manned helicopter consumes more fuel than UAS during these critical stages of the flight.

Aircrew

The capabilities and risk to manned aircraft pilots and aircrew in the civilian world are vastly different and higher than to UAS pilots/operators. These differences are reflected in the labor costs of such pilots, which may account for their dissimilar physical and mental health requirements, training, salaries and insurance fees. For a variety of reasons, it is very hard to compare the cost-effectiveness of using UAS versus manned aircraft. This task becomes even harder when it comes to theoretical exercises such as suggesting supplanting a manned aircraft with UAS as this vignette is proposing in the case of the chilled aerial release program in the Niayes in Senegal. Nevertheless, as the comparison in training and wage costs between helicopter and UAS pilots implies, obviating the need for aircrew would lower the cost of labor.

Training

UAS pilots differ by class—while large military and/or commercial UAS of HALE or MALE classes are flown by highly-trained pilots, MAV, LALE and LASE can be practically operated by anyone. Some of the models defined as “hobby drones” do not require even minimal training. In contrast, pilots onboard commercial aircraft, including helicopters, are usually highly trained individuals, whose physical and mental health meets certain requirements, and whose reservation wage is relatively high.

While examining pilot training options in Africa would have been the reasonable approach in this vignette, given the absence of Africa-specific data the information in this section is based on data from the United States. Indeed, the scale is likely to be different; however examining the different training requirements and cost in the United States can shed light on the differences between manned aircraft and UAS.

Theoretically, to fly the Magni M-16 Gyrocopter currently employed in the Niayes region, training is available at $2,600 per person. However, having Private Pilot License (PPL) or Recreational Pilot License
(RCL) is a prerequisite for flying the gyrocopter. And this training is considered a specific add-on. It is therefore reasonable to assess the costs of obtaining a PPL or RCL.

There are countless pilot training programs in the United States and abroad that differ in their requirements and rates. In the United States, all programs require that students be over a certain age (usually 17), obtain FAA medical certificate, enroll in ground school and theoretical subjects (such as navigation), and complete flight training of dozens of hours. For example, a private helicopter license can be obtained after 50 hours of ground school, and 35–55 hours\(^\text{cclvi}\) flying at an hourly rate of $300, amounting to approximately $10,500.\(^\text{cclvi}\) Together with the add-on Magni training, the cost of acquiring a gyrocopter flying license in the USA is approximately $13,000.

Unlike the military domain, where UAS pilots are trained and subject to formal requirements similarly to manned aircraft pilots, the civilian UAS world is governed by significantly less uniform standards for pilot/operator training\(^7\). Still, to put the difference between civilian manned and unmanned pilot training in context, it is useful to look at an example of UAS pilot training program in the USA, such as the one offered by the Unmanned Vehicle University. Unlike add-on trainings for different types of manned aircraft, this program requires no previous experience prior to enrollment.

A UAS pilot training certificate can be obtained in three phases, with phases 1 and 2 being completed at students’ homes. In Phase 1, students learn the sUAS Ground School which covers basic topics such as checklists, general characteristics, wireless links, emergency procedures and so forth. In phase 2, the company provides students with a simulator, which consists of software and a controller that plugs into the computer USB port. The simulator allows “flying” 47 different small UAS, including fixed-wing and rotor wing aircraft, from six different sites. Students will receive instruction on both fixed wing and rotor wing aircraft. Instructors are available to assist students via phone. In the third phase, students spend two days at the school where they fly sUAS. At the end of the program, students receive a UAS Pilot Certificate that shows 10 hours of simulator, 16 hours of ground school and 16 hours of flight training for a total of 50 hours of training. The program costs $3,500.\(^\text{cclviii}\) The difference is the cost of training between the manned and unmanned aircraft is roughly $9,500 per pilot. This difference may not reflect requirements to fly all types of UAS and previous experiences of pilots (for example, presumably former UAS military pilots will need significantly less training to operate civilian UAS).

Wages

According to salary.com, the annual salary for “Helicopter Pilots” may vary depending on a number of factors including industry, company size, location, years of experience and level of education. Based on survey data collected from thousands of human resources departments at various companies and

\(^7\) According to the FAA, commercial UAS require the operator to have certified aircraft and pilots, as well as operating approval. Nevertheless, flying UAS for “hobby” or “recreational” purposes does not require FAA approval and hence, standardization in terms of training is still lacking. See FAA, Busting Myths about the FAA and Unmanned Aircraft.
industries the range of helicopter pilots in the UAS is $60,000–132,000 with the median of $85,737.\textsuperscript{cclix} The website Indeed.com estimates the salaries of UAS pilots—formally trained to remotely fly and not considering untrained operators—as ranging between $30,000 and $70,000.\textsuperscript{cclx}

Again, this comparison has two limitations. First, it draws on U.S. data and thus may not reflect salaries in Africa. Yet, it can still be informative on percentage differences between the two types of pilots. Second, the wages of UAS pilots are likely also to be category-dependent. For instance, only former military UAS pilots or quad-copter fliers may be able to fly certain types of UAS and their wages will assume to reflect their background and experience. On the other hand, other and more highly-automated systems may require less operator skills, which will also be reflected in wages (and training costs).

**Maintenance Costs**

In the military realm, maintenance costs for both manned and unmanned systems are similar and high.\textsuperscript{cclxi} As indicated in Section 3.1.2, civilian UAS are typically commercial off-the-shelf (COTS) and may have less stringent safety requirements.\textsuperscript{cclx} Thus, we can assume lower maintenance costs for UAS.

**UAS Potential Fit**

While the gyrocopter is advantageous for the chilled aerial release missions relatively to other helicopters, this crude analysis demonstrates the merit of examining UAS as a potential substitute. Indeed, in terms of fixed costs, UAS may be comparable or even higher than the currently-used gyrocopter. However, the operational costs including fuel, aircrew labor—training, wages and insurance (which would be required for aircrew), and maintenance are lower for UAS. Any cost savings can have utter importance for a poor country such as Senegal who is fighting to eradicate the Tsetse fly population and address food security and economic challenges.

**Flight Range**

The Niayes region is a strip of land, 9–17 miles wide, along the coast. Like the entire coastal region, this area is characterized by the overlapping of two geomorphological features. The dunes alternate with longitudinal depressions, locally named niayes, and form a hilly region. While the comparison throughout this vignette analysis focused on helicopters, the gyrocopter and as an example the Ag-210, which are better for sterile fly release than fixed wing aircraft in mountainous areas, the terrain does not impose a strict limitation on the type of platform, and fixed-wing UAS may potentially be suitable as well.

The target area in terms of Tsetse distribution is 386 square miles.\textsuperscript{cclxii} The area was divided in the trial into four blocks and each block was subdivided into polygons where the release density and rate can be adjusted on the MSRM2 according to the number of suitable Tsetse habitats (Figure 3.5). An example of a polygon size is 8,100 hectares,\textsuperscript{cclxiv} or 31 square miles. As mentioned earlier, sUAS cannot fly this range at a low altitude due to communication challenges. On the other hand, unmanned VTOLs and medium sized UAS are potentially compatible although their employment for the range of the task may also
require innovative solutions such as using more affordable SATCOM or cellular networks, or autonomous operation of the UAS it drops in altitude to dispense the flies, i.e., when it is beyond LOS.

**UAS Potential Fit**

Medium sized agricultural UAS and unmanned helicopters can potentially meet the range requirement.

**Figure 3.6 Division of Niayes Target Area into Blocks and Polygons**

SOURCE: Mubarqui, Ruben Leal et al.

**Release Airspeed**

In the Niayes program, to ensure good dispersal of lies the distance between releases was designed to be lower than the swath width which was defined as 0.31 miles. The gyrocopter flies at airspeed of 68 miles per hour. This falls closely within the average release speed in pilot programs which is 70 miles/hour. Airspeed during release varies according to program, region, release machine, and so forth. Nevertheless, the airspeed should ensure optimal release of sufficient quantities of functional sterile flies where they are needed. As indicated in Section 3.5, many UAS can fly at this speed including the Ag-210.

**UAS Potential Fit**

Agricultural UAS meet the release airspeed requirement.

**Altitude**

The altitude selected for the Niayes program based on experiments was 328 ft., a requirement that can be met even with amateur UAS. The ceiling altitude of unmanned VTOL’s, including those designed for agricultural missions, is on average 10,000 ft. (1.8 mile). The challenge as explained earlier is the balance of range versus altitude.

**UAS Potential Fit**

Agricultural UAS, including helicopters, meet the altitude requirement.
Release Accuracy
As explained earlier, to minimize human error, the release machine itself is equipped with a navigation system that guides the pilot to the release areas (presented as polygons). This system also contains the logging, measurement and automation of the release. Finally, the machine has video cameras for confirmation that the flies are indeed being released. Hence, in terms of release accuracy, it is insignificant if the platform on which the machine is mounted is manned or unmanned.

UAS Potential Fit
UAS are suitable for this task just as manned aircraft.

Ground Facility Requirements
While ground crew is still needed, many UAS can be transported by a single person. For instance, according to the manufacturers, the Ag-210 can be easily transported (and operated) by one person. The gyrocopter used in Senegal is larger (Table 3.5) and thus may require either flying to destination or more complicated transport and logistics. In the Niayes region, the analysis assumes a two-member ground crew whereas three members are required to facilitate the flight of the gyrocopter.

UAS Potential Fit
UAS may offer cut down the requirement for ground crew by third thus contribute toward cost savings.

Safety
As in the more general case, the potential use of UAS for low altitude missions is safer than manned aircraft because mishaps do not lead to injury and loss of life to aircrew. Helicopters in general are considered dangerous and gyrocopters are no exception. In Australia, eight accidents were documented in 2013, and seven during 2012, many of which were fatal. Worldwide, 48 gyrocopter accidents were documented worldwide.

UAS Potential Fit
In the Niayes region, as in anywhere else, moving aircrew out of harm’s way is an advantage that UAS have over manned aircraft.

Vignette Analysis Conclusion
In similar to the general case examining the potential fit of UAS for chilled aerial release, medium sized and VTOL UAS can meet most if not all the needs of the specific SIT program in the Niayes region in Senegal. As demonstrated, UAS’ performance characteristics such as airspeed, ceiling, weight, range etc., comply with the requirements of the chilled aerial stage. Further, except for their comparable fixed costs, UAS represent potential improvements over manned aircraft in terms of operational costs, environmental burden and safety.

To provide more context, this vignette primarily drew on a comparison between the Magni gyrocopter employed in the trial phase in the Niayes region and the unmanned agricultural VTOL, Ag-210. The Ag-
210 is potentially capable of fulfilling the core requirements of the aerial release stage and seems comparable to the gyrocopter currently used in the Niayes. While this analysis by no means advocates the use of Ag-210, this approach may be employed to compare between any UAS and aircraft currently-used in such missions.

3.6 Conclusion

This chapter used a mixed-method approach to examine the compatibility of UAS to assist in Tsetse fly eradication programs in Sub-Saharan Africa. Following extensive background research on the Tsetse problem, on currently available means of addressing it, and on UAS technology offerings, I utilized a systems engineering approach and a vignette analysis to assess if UAS specs can meet the requirements of SIT aerial release requirements, and gauge the potential performance of UAS in comparison to manned aircraft currently employed in such missions.

Based on the analyses performed, UAS comply with most of the requirements of SIT programs and can supplant manned aircraft in aerial release. As demonstrated in Table 3.4, they may not only be more cost effective but also provide added value in terms of environmental damage and safety. These findings apply to general aerial release case as well as the particular case of the Niayes region in Senegal.

Nevertheless, given the weight requirements and the communications range limitation, sUAS are currently not suitable to carry such missions. Instead, medium sized UAS and unmanned helicopters (that can carry a relatively large payload) are more appropriate. The challenge with such UAS types is that they are more costly, require more operational expertise (which can also be translated into costs in terms of training requirements and wages), and are likely to fall under stricter legal requirements than sUAS (even in countries where there is a legal vacuum around this issue).

There are two limitations to this analysis. First, it relies on U.S. data (pilot training, wages, and other) however these are likely to be different than in Africa. Second, in considering the potential fit of UAS for Tsetse eradication programs, this chapter did not consider non-technical barriers to adoption of this technology including perceptions of farmers, the legal status of UAS across countries Africa, and others. Chapter 4, which assesses whether UAS can be used in the human–wildlife conflict with pest birds in Africa, extends beyond the technical dimension and assesses the potential fit of this technology taking into consideration other drivers and barriers to adoption.
Chapter 4. UAS for Management of Human–Wildlife Conflict: The Red-Billed Quelea Bird

4.1 Introduction

The second potential agricultural UAS delivery mission examined in this study is human–wildlife conflict management, in particular with the pest bird Red-Billed Quelea, an endemic species to Africa. As will be discussed in detail in the next section, the Quelea is the most abundant bird species in the world. It is nourished on annual grasses, seeds and grain, including millet, sorghum, rice, wheat and more and has developed migratory strategy that ensure year-long feeding. The Quelea not only a major threat to subsistence small grain crop farmers, and of economic importance to commercial farmers in Sub-Saharan Africa, but it has also been recognized as having a direct negative impact on food security in the region. Quelea flocks attack on average twice per year and remain in an area for six weeks at a time, during which crops are vulnerable from dawn until dusk. The Quelea breeding and feeding habits have given this species its nickname the “feathered locust” and “Africa’s most hated bird.”

Traditional means of eradicating Quelea populations have centered around two main strategies: First, lethal actions, using either large-scale spraying of infested areas with chemicals, or blowing them up with bombs or dynamite. This strategy has proved both ineffective as well as extremely non-environmental friendly. Otherwise, small-scale farmers have relied on the age-old method of scaring the birds using catapults and making noise. While this approach is relatively effective, and certainly more environmentally sustainable, it is highly labor-intensive and time-consuming.

The purpose of this chapter is to examine whether UAS can substitute human labor in scaring Queleas away from farmland and thus quell the staggering damage to small grain crops caused by this bird in Sub-Saharan Africa. Considering multifaceted nature of this prospect, this chapter extends beyond technical assessment of whether this potential UAS solution can meet the Quelea challenge, but also analyzes the non-technical feasibility of adopting this technology for this mission.

The remainder of this chapter is organized as follows. Section 4.2 describes the scope of this chapter and its structure, and provides an overview of the methods employed in each of the subsequent sections. Section 4.3 presents background information on the Red-Billed Quelea and its detrimental effect on agriculture in Sub-Saharan. Section 4.4 reviews the literature on strategies employed in management of human–wildlife conflicts with bird flocks. Section 4.5 builds on this literature and integrates expert judgement to assess whether UAS is technically capable of addressing the Quelea problem. Sections 4.6 and 4.7 describe the field study I conducted in Kenya to examine stakeholders’ perceptions regarding the feasibility of adopting agricultural UAS for Quelea control. The former section explains the methods employed throughout the field study whereas the latter reports its results. Section 4.8 discusses these findings and concludes the chapter.
4.2 Scope of Chapter and Overview of Approach

To study the potential fit of UAS for Quelea-bird control, this chapter adapted phases 1–4 of the research plan (highlighted in yellow), which was first outlined in Chapter 1 and is illustrated again in Figure 4.1.

The first three phases of this research plan are designed to be similar to those carried out in Chapter 3 to assess the compatibility of UAS to suppress the Tsetse problem. At the same time, they are different in one important way. While in the case of the Tsetse fly there is currently an operational comparable technology—manned aircraft executing aerial release as part of SIT programs—against which UAS can be evaluated, there is no such alternative in the context of the Quelea. Therefore, a systems-engineering approach similar to that introduced in Chapter 3 to “match UAS technology specs with agricultural requirements, and assess UAS performance against comparable technologies employed for similar missions” could not be employed at this stage.

Instead, this chapter used a mixed-method approach that included primarily literature review, field survey and in-depth interviews. These methods helped elucidate three areas of prime importance to this
chapter’s objective—assessing the potential fit of UAS to address the Quelea problem. These areas are as follows:

1. The characteristics of the Quelea challenge—corresponding to Phase 1 of the research plan, i.e., identifying the agricultural challenge;
2. The potential compatibility of UAS technology for Quelea bird-control—corresponding to Phases 2 and 3 of the research plan, i.e., examining potential UAS solution and assessing to what extent they match the problem;
3. And possible drivers and barriers to adoption of UAS technology for this purpose—corresponding to Phase 4, i.e., adoption feasibility analysis.

Subsequent sections will elaborate on the methods and data sources utilized to study each of these key components, as listed in Table 4.1. In short, the analysis described in this chapter began by reviewing existing research on the Quelea bird and common currently-used strategies of human–wildlife conflict with bird flocks. This review has helped understanding the potential use of UAS in Quelea-control as well as identified gaps in current research. Subsequently, the scarce literature on the use of unmanned aircraft for bird control was surveyed. To fill in this void in research, I conducted in-depth interviews with several subject matter experts (SMEs) with relevant knowledge in this field.

<table>
<thead>
<tr>
<th>Key Study Component</th>
<th>Research Methodology</th>
<th>Data</th>
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<tbody>
<tr>
<td>Phase 1: Quelea challenge</td>
<td>Literature review; interviews with Quelea SMEs; survey of smallholder farmers in Kenya; in-depth interviews with stakeholders (farmers, government, NGOs)</td>
<td>Secondary data (from literature); primary quantitative data (from survey) and qualitative data (interviews and survey)</td>
</tr>
<tr>
<td>Phases 2&amp;3: Potential fit of UAS to address Quelea challenge</td>
<td>Literature review; interviews with Quelea and UAS SMEs</td>
<td>Secondary data (literature); primary qualitative data (SME interviews)</td>
</tr>
<tr>
<td>Phase 4: Drivers &amp; barriers to UAS adoption for Quelea control</td>
<td>Survey of smallholder farmers in Kenya; in-depth interviews with stakeholders (farmers, government, NGOs)</td>
<td>Primary quantitative data (from survey) and qualitative data (interviews and survey)</td>
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Findings from the literature reviews and interviews with SMEs indicated that the main sufferers from the Quelea problem are poor smallholder farmers, and that popular Quelea control methods are extremely low-tech. Thus, to contextualize this exploratory study and analyze the feasibility of adopting UAS for this mission, I conducted a field study in Kenya where I surveyed and interviewed various stakeholders. The objective of both the survey and interviews was to collect inputs and perspectives of stakeholders regarding possible drivers and barriers that may influence the adoption of UAS technology to alleviate the Quelea challenge. The data collected through the survey was analyzed quantitatively and qualitatively whereas the data collected via the various types of interviews was subject to qualitative query.
Kenya was selected for this study for various reasons. First, smallholder farmers (i.e., owners of farms that support only their own family with a mixture of cash crops and subsistence farming) are severely affected by the Quelea problem. Moreover, Kenya has recently obtained UAS capability—the US government gave Kenya eight Raven UAS\textsuperscript{8} to fight terrorism,\textsuperscript{cclxxvi} and several governments including the US are helping Kenya fund the use of UAS for anti-poaching throughout the country’s national parks and reserves.\textsuperscript{cclxxvii} Further, different stakeholders in the country have expressed a-priori interest in collaborating on such a study.\textsuperscript{cclxxviii} The combination of an imminent problem with the awareness of a potential solution made Kenya an optimal venue for such an assessment.

4.3 Human–Wildlife Conflict with the Red-Billed Quelea

Human–wildlife conflicts are defined by the interaction between wild animals and people, which result in a negative impact on people or their resources, or wildlife or their habitat. In contrast to pests however, the wildlife involved in conflicts with humans may often be also considered as a resource,\textsuperscript{cclxxix} from which humans may benefit positively (ecologically, economically, scientifically or recreationally).\textsuperscript{cclxxx} Various species around the world are in conflict with human populations (e.g., baboons in Namibia that attack young cattle, orangutans in oil palm plantations, and bears and wolves in Europe that kill livestock). Many such conflicts involve large bird flocks—most commonly addressed are geese, starlings, gulls and rooks—which damage fruit trees, feed on livestock food supplies, and cause severe damage to crops.\textsuperscript{cclxxxi}

One of Africa’s most pressing—and most poorly addressed—human–wildlife conflicts is farmers’ ongoing struggle with the Red-billed Quelea (\textit{Quelea Quelea}). Even though the Quelea is considered as a benign source of protein that is often eaten by people in rural regions, as well as sold in commercial markets in some countries such as Zimbabwe, Cameroon and Chad,\textsuperscript{cclxxxii} its damages significantly outweigh its benefits throughout Sub-Saharan Africa.

The Quelea is the most abundant wild bird species in the world,\textsuperscript{cclxxxiii} forming huge colonies consisting of up to 30 million birds, with an adult breeding population estimated at 1.5–5 billion pairs.\textsuperscript{cclxxxiv} Their breeding season begins with seasonal rains, which come at different times in different areas, and thus last for many months. The Queleas may breed several times in the same season, depending on local food supply. Intensive farming and an increase in cereal crop production throughout the continent resulted in an explosion in their numbers; according to some estimates Quelea populations have increased anywhere from 10 to 100 times since the 1970s.\textsuperscript{cclxxxv}

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\textsuperscript{8} The Raven, produced by AeroVironment, is the world’s most widely used UAS. It is a hand-launched system which provides aerial observation for military applications requiring low-altitude surveillance and reconnaissance intelligence. Source: AeroVironment
The species is nourished on annual grasses, seeds and grain, including millet, sorghum, rice, wheat, maize, oats, buckwheat, as well as crushed maize from cattle feedlots. In particular, it is considered as a significant pest of small grain crops throughout sub-Saharan Africa and is therefore a major threat to subsistence farmers and of economic importance to commercial farmers. Officially in recent years it has become recognized as having a direct negative impact on food security.

Queleas can move 30–40 miles in a single day to feed and then return to their roost at night. Since preferred grass species are annuals, Queleas have developed a migratory strategy to ensure year-round feeding. By eating intensively, Queleas can gain sufficient weight to allow migration to new feeding areas. Their breeding and feeding habits have given this species its nickname the “feathered locust” and “Africa’s most hated bird.”

The native range of Queleas extends over some six million square miles in Africa and includes the Eastern part of the continent (e.g., Ethiopia, Mozambique, Rwanda, Zimbabwe, and Kenya); Central Africa (e.g., Angola, Chad, Cameroon, Congo); Western Africa (Benin, Burkina Faso, Côte d’Ivoire, Nigeria, Mali) Southern Africa (e.g., Botswana, South Africa, Namibia); and Sudan in Northern Africa.

Each individual Quelea bird consumes half to its whole body weight in seeds each day, and as a flock, Queleas are capable of destroying entire crops, over areas up to 1,000 hectares. The most recent estimate of the agricultural losses attributable to the Quelea is equivalent to US$79.4 million per annum at 2011 prices throughout semi-arid zones of Africa. Nevertheless, SMEs interviewed for this study contend that this figure utterly underestimates the crop damage.
Furthermore, the physical damages fail to capture the true economic losses associated with the Queleas as they do not account for costs faced by farmers who avoid cultivating traditional cereals and have instead shifted to growing the less reliable and less nutritious Maize because it is more resistant to Quelea attacks. Reliance on maize as staple crop partially explains food insecurity in Africa. In Zimbabwe for example, many subsistence farmers in semi-arid areas have planted maize instead of the better-adapted sorghum and millet, with zero harvest potential, forcing the country to need food aid programs.

4.4 Management Strategies of Human Conflict with Bird Flocks

To understand whether UAS may offer a solution to manage the Quelea problem, it is useful to review common methods used to deter birds worldwide. These methods can be crudely divided into preventive and protective types. While the former focus on preventing crops from arriving in the fields the latter aim at protecting crops when birds are already present in the immediate surroundings, as described in the next section.

4.4.1 Preventive Bird Control Methods

Preventive measures can be subdivided into lethal and non-lethal techniques:

Lethal Techniques

Aimed at suppressing pest bird populations by nest destruction, treatment with chemicals lethal to birds, and the use of explosives. These are usually implemented by national or regional government agencies and are carried out via ground or air, employing manned aircraft for spraying roosts and/or breeding colonies. While premature at this stage, future research may seek to examine to what extent UAS can supplant manned aircraft in such missions.

Large scale chemical control methods to reduce the population size of the Queleas are common in Africa. However, in many cases those cannot compete with the Queleas' immense reproduction potential and high mobility. Moreover, areas in which birds inhabit are often inaccessible to humans thus limiting the effectiveness of such tactics. South Africa prides itself in being an exception. According to government agencies, it is one of the most efficient countries in the lethal control of the Queleas, using chemical spraying and explosives to kill 40–100 million individual birds per annum since the 1950s.

Finally, lethal techniques cause severe environmental damages as not only-target species may be affected directly by spraying, but predatory birds, scavenging birds and even mammals can be contaminated by secondary poisoning when they eat Quelea carcasses. Even in South Africa, a public
outcry over spraying the chemical fenthion\textsuperscript{9} along the Gariep River\textsuperscript{10}, which caused serious damage to biodiversity in the area, led the government to limit the extent and range to which it uses the chemical.\textsuperscript{ccci}

Another lethal control method is harvesting Queleas as a source of protein. It is considered benign and could contribute to local nutritional and economic needs. Not only do rural people traditionally collect and eat Queleas in different parts of Africa, but commercial Quelea markets have been developed in Cameroon and Chad. In rural Chad, trapping and selling Quelea for food is an important economic activity. In 2000, some seven million Quelea birds were trapped and sold, accounting for 40 percent of the maximum capitalized crop loss experienced by farmers.\textsuperscript{ccci} However it is unlikely to reduce Quelea populations substantially.\textsuperscript{cccii}

Non-Lethal Techniques

Those include agronomic practices such as vegetation management, weed management, and diversifying crops with bird-resistant crops. In addition, religious techniques such as shamanism are still being employed throughout Africa to prevent the appearance of the Queleas.\textsuperscript{cccv}

\textbf{4.4.2 Protective Bird Control Methods}

Protective measures can be broken down into five categories - netting, repelling, natural predation visual scare tactics, and auditory scare tactics, as explained briefly below:

\textbf{Netting}

This strategy is mostly used in vineyards which are also vulnerable to pest birds. It consists of covering the threatened area with nets to provide a physical barrier. In vineyards, each vine is wrapped until harvest, when the netting is removed immediately before grapes are picked. This method is considered effective, but is also very labor intensive and expensive.\textsuperscript{cccv} In Africa, it has been tried using nets and wires but it is not a feasible option for protecting large crop fields due to the costs associated with nets.

\textbf{Repelling}

This tactic refers to the use of repellents, chemical substances aimed at deterring birds, which are sprayed directly on the crops.\textsuperscript{cccv} Not only do the chemicals need to be non-poisonous, but also birds may easily get accustomed to them thus limiting their effectivity beyond the short-term.

\textsuperscript{9} Fenthion is a chemical substance extremely toxic to birds and aquatic life in general.
\textsuperscript{10} The Gariep River, also known as the Orange River, is the longest river in South Africa. The river forms part of the international borders between South Africa and Namibia and between South Africa and Lesotho, and flows through South Africa to the Atlantic Ocean.
Natural Predation
Refers to using birds to hunt pest bird populations from the air. Vineyards in the United States often lease predators, usually falcons and raptors, to keep away pest birds. This method is useful but costly. In Africa, Quelea colonies attract multiple predators primarily raptors, herons, storks, hawks, and owls. There are several factors limiting the use of natural predation in the case of Queleas, most important of which is its flocking behavior which reduces individual birds’ risk of predation by having a flock swamp potential predators. Moreover, such a tactic is unlikely to quell the problem and reduce the population size significantly.

Visual Scare Tactics
Deter birds with flashing lights, sudden movements, using objects including eyespots, flash tape, and lasers. While considered highly effective, the major limitation of all visual scare tactics is that they are effective until birds habituate to them. That is, the visual stimuli are either too stationary or too regular in their disruption leading to birds’ gradual habituation to them.

- Flash tapes: those are long, reflective streamers commonly used in visual scare tactics. The streamers catch sunlight and appear to change color as they move around in the wind. Birds are startled by the changes in light and tend to avoid areas with bright moving objects.
- Lasers: the use of lasers has shown to be effective in bird control as birds tend to get confused by moving lights that have no tangible sources.
- Floating scarecrows: large, intimidating eyespots arranged horizontally, are placed on balloons to mimic the general appearance of large predators’ eyes.

Auditory Scare Tactics
Deter pest birds with sound-based techniques. Such sounds can be either: startling noises, e.g., shotgun or gas canon blasts; or bioacoustics—sounds of birds in stress which are either recorded or mimicked and then played when bird flocks are present. When a bird feels threatened or is startled, it tends to alert other birds around it with a distress call which tells other birds in the area that the location is not safe and, as a result, the birds all flee. By playing back these calls, bioacoustics-based deterrence techniques trick bird flocks into thinking they are in presence of danger.

Generic audible scare tactics—primarily the startling sounds—are considered effective and simple to use. However, as with visual scare techniques, birds become acclimated and cease reacting to them at some point. Methods to delay habituation include changing the location of devices, altering the periodicity of stimuli or the use of a combination of devices. Both however can be very time consuming. The specificity of bioacoustics makes it promising, as birds (and other animals) are less likely to habituate to their own alarm and distress calls.

Sophisticated bioacoustics-based systems are the Scarecrow Premier 2020 and 1500 that are employed in airfield wildlife management. The systems, which broadcast distress calls as part of an integrated bird management scheme, have proved “effective for bird dispersal from airfields and surrounding...
areas. While cost-efficiency in airports is surpassed by safety considerations, the high price of this system makes it impractical for agricultural production.

In agriculture, frightening devices utilizing bioacoustics-based stimuli have been used in various applications including protection of cornfield and soybean field protection. The GooseBuster is a commercial system which uses bioacoustics and is specifically tailored for Canada geese. The system is based on alarm, alert and distress calls which are played back from multiple speakers in ways that ensure variable stimuli. In assessing the performance this system, it was found that geese moved up to a 300 feet away from the device but never left the area. When comparing the steady sounds to suspended crow carcasses, distress calls proved to be very effective, whereas the carcasses had no effect. Even though habituation to bioacoustics has been reported, species-specific alarm and distress calls are more resistant to habituation than other sounds.

Research in the area of bird control recommends an integrated pest management (IPM) approach that consists of several techniques as neither one can single-handedly mitigate human conflict with birds. This is also likely to be true in the case of the steadily growing population of the Queleas across Sub-Saharan Africa despite ongoing large scale suppression efforts.

4.5 To What Extent Are UAS Technically Compatible for Quelea Control?

As demonstrated in Section 4.4, a wide range of devices and methods are used in management of human–wildlife conflict with bird flocks; however, their sustainability is limited either due to habituation on the part of the birds, or due to the damage these methods inflict on the environmental. The research community in this area thus continuously seeks to develop more effective, ethical and environmental-friendly methods for wildlife damage management.

The objective of this section is to assess whether UAS technology can technically provide a potential solution for the Quelea problem. To do so, this section draws on the scant evidence on UAS use in bird control and uses data collected in interviews with seven SME. Three of the SMEs specialize in the Red-Billed Quelea and are academics living and working in Sub-Saharan Africa where they frequently research these bird species. These experts were identified by grain crop researchers with whom this author have been corresponding regarding food security challenges in Africa. They all publish relatively frequently on this issue and their articles are cited throughout this chapter. The other four SMEs have expertise in UAS technology. Two of them are from academia whereas the third is from the private sector and specializes in bird control methods, including such that utilize unmanned aircraft. The background research and literature review on bird control methods helped identify these UAS experts.

These expert interviews provided insight into the vulnerabilities of the Quelea birds and potential mitigation approaches as well as helped assess whether UAS may be technically suitable to address this problem. While the SMEs were not specifically asked about factors that can influence implementation, e.g., the technical capabilities of farmers, regulation and costs, the semi-structured interview format
helped gain their valuable insight on such issues as well. Interviews were conducted over the phone and detailed notes were taken to capture insights as well as accurate quotes when appropriate. Appendices B and C provide the interview protocols with the Quelea and UAS SMEs, respectively.

4.5.1 Potential Use of UAS as Protective Bird Control Measure

Early research on potential UAS uses in wildlife management suggests that this technology can be applicable to handle nuisance birds. It can be employed to disperse bird colonies by scaring them away from centers of human activity and agricultural lands via emission of sounds. As mentioned above, the Scarecrow Premier systems have been utilized in airports and although based on remotely-controlled aircraft (RCA) technology, they provide an example for how small unmanned aircraft can scare birds away. Another example of an audible scare tactic device available on the market is BirdXPellar Predator Drone, developed by BirdX, Inc.’s, which combines BirdX’s existing auditory bird scaring system with the mobility of an RCA. The BirdXPellar uses a speaker system attached to its airframe to broadcast loud bird distress call audio tracks while being flown manually. To avoid becoming too predictable, the BirdXPellar UAS is equipped with several different distress call sound bites.

Based on examination of existing technology and SMEs input, the UAS envisaged for scaring away Queleas would be a relatively small fixed-wing aircraft that would combine visual and auditory stimuli and fly at a low altitude. Clearly, an experiment would be needed to determine what attributes, if any, would make a UAS compatible as a protective Quelea-control measure. However, theoretically the envisaged UAS would have the following characteristics:

Visual Design

The UAS would be designed as one of the Queleas predator birds. According to SMEs and literature, while the species officially has many predators, the main ones are falcons, herons and eagles. The UAS SMEs interviewed suggested capitalizing on existing predatory bird–like systems for scaring off Quelea flocks. Two such systems for example are the EPP Peregrine, an RCA designed to look like a peregrine falcon to scare away pest birds, and the BirdXPellar Predator Drone, introduced above (Figure 4.3).
Auditory Stimuli

Both literature and SMEs note the importance of sound, as explained by one SME: “Sound is the key, Natural predators and birds in distress conditions signal to birds to stay away from the area because it is dangerous.”

In particular, birds habituate more slowly to their own species-specific alarm and distress calls than other sounds, including generic bird ones. Therefore, it is suggested that this UAS would be mounted with speaker that emits two types of sounds—of a Queleas’ predator (the one selected for visual design of the airframe) and Queleas’ distressed sounds. According to the Quelea SMEs, these birds become distressed in the presence of snakes (which attack their eggs and young) and make unique sounds which may be recorded. Further, under “extreme” circumstances Queleas make a “screaming noise,” which may also be recorded. The speaker used on the BirdXPellar weighs 0.3 lb. and its dimensions are 3.75”x3”x3”. It is attached to the airframe with Velcro. A similar solution can potentially be employed here.

Size

The dimensions of the BirdXPellar are 59”x32” and it weighs 7 lb. considering the enormous size of Quelea flocks, and the rough conditions in rural Africa, it is speculated that a larger and more robust airframe may be needed. An example for such system is the Silent Falcon sUAS, which weighs 30 lb. and measures 80.8”x22.4”x15.” This option is considered easily transported in back of pickup truck, large SUV or Humvee.

Endurance

The BirdXPellar is operated on batteries that need recharging every 15 minutes. One SME noted that one of the features giving the BirdXPellar its authentic predator look is the finger-like structure of the tips of its wings. However, such a design is aerodynamically inefficient. An alternative option is to have a sUAS with standard flat tips of wings and to draw wing shapes on them. Yet, short endurance is often a
shortcoming of sUAS. Given that Quelea flocks tend to stay in an area for approximately 12 hours per day, the UAS developed should be able to remain in the air for at least several hours before recharging. Thus, a solar-powered UAS can potentially offer a solution and the Silent Falcon sUAS again is cited as an example. The Silent Falcon has solar wings which provide the propulsion systems with significant lightweight electric energy and build an endurance of eight hours.\textsuperscript{cccxxxii}

Altitude
The UAS would fly at low altitudes which are to be determined in an experiment. If the UAS design mimics a predator, it is hypothesized that it should fly above a flock either directly or slightly from afar.

Range
The BirdXPellar scares bird flocks away from a distance of a quarter or half a mile away, based on videos on the company’s website. The UAS for Quelea control would ideally also be effective as a deterrent from afar and would not engage in close contact with bird flocks. Otherwise, according to experts, it is plausible to assume that the birds would either attack the UAS, or they may become lodged in the air intake of the UAS. The outcome of both types of incidents would be the crash of the UAS. Another consideration which would have to be tested in an experiment is whether the UAS chases the birds where they go, even when they are no longer within line of sight. In that event, the UAS may or may not require a camera onboard which adds some complexity and raises the power requirement.

4.5.2 Potential Use of UAS as Preventative Bird Control Measure
UAS can also potentially be used in preventive control methods, including in surveying Quelea roosts in preparation for lethal control actions or spraying roosts and/or breeding colonies with chemicals, as suggested by two Quelea SMEs. Their motivation for pursuing preventive control measures is that protective control measures are considered only moderately effective, especially given how labor-intensive and time-consuming they are. The experts acknowledged that notwithstanding their effectiveness, lethal methods cause environmental damage. In addition, the extent to which preventive lethal methods are effective is varied, depending on country and area. An expert from South Africa, where preventive lethal methods are exercised frequently and are reportedly effective, said that timing is a critical factor:

If the control teams get to a colony or a roost in time they can be successful but often they arrive too late or their control efforts don’t kill enough of the birds to make such difference. Control is very good in South Africa, reasonable in Botswana and Tanzania, poor or non-existent in West Africa.

The potential compatibility of UAS for such a lethal approach and how this technology may compare to manned aircraft currently spraying the birds from the air with chemicals was not examined in detail in this study. Nevertheless, it is important to note that the assessment tool developed and employed in Chapter 3 to examine the feasibility of employing UAS to help eradicate Tsetse fly populations can also be useful in the context of the Quelea problem. In particular, such an exercise would include the following steps:
1. Understand the requirements of the mission. For example, what is the weight requirement given the necessary chemical spraying equipment? Does this weight vary by bird colony size? Other requirements include but are not limited to altitude, range, ground facility requirements, and communications.

2. Survey the types of manned aircraft currently-used in surveying/spraying missions;

3. Identify if, and which, UAS may meet such a Quelea mission requirements and compare this potential performance to manned aircraft currently employed in similar applications using a methodology similar to the one developed for the Tsetse issue, as shown for example in Table 4.2. If the surveillance mission is analyzed, such a comparison should be conducted not only against manned aircraft but also against satellite imagery.

4. Based on the potential compliance of UAS with the requirements, color-code the cells appropriately to indicate how it is compared with that of manned aircraft. The stoplight chart colors could help illustrate how well UAS may fulfill the aerial chemical spraying needs in comparison to manned aircraft. The bright green color denotes excellent match and improvement; yellow indicates average quality match and marginal improvement over manned aircraft, and red signals a mismatch (Table 4.2).

<table>
<thead>
<tr>
<th>Requirement</th>
<th>UAS Compliance</th>
<th>Requirement</th>
<th>UAS Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td></td>
<td>Ground Facility</td>
<td></td>
</tr>
<tr>
<td>Environmental Burden</td>
<td></td>
<td>Safety</td>
<td></td>
</tr>
<tr>
<td>Fixed Costs</td>
<td></td>
<td>Release Airspeed</td>
<td></td>
</tr>
<tr>
<td>Operational Costs</td>
<td></td>
<td>Weather Conditions</td>
<td></td>
</tr>
<tr>
<td>Flight Range</td>
<td></td>
<td>Accuracy</td>
<td></td>
</tr>
<tr>
<td>Altitude</td>
<td></td>
<td>Communication</td>
<td></td>
</tr>
</tbody>
</table>

### 4.5.3. Potential Compatibility of UAS for Quelea Control

Overall, experts thought that UAS seem compatible to mitigate Quelea problem especially as a protective measure (employed to scare away Queleas). They have shown interest in collaborating on future research on this idea and have asked to remain involved in ongoing efforts. For example, as one expert put it: “This project seems very interesting. We would certainly be very interested to collaborate on this project.” Another expert said that the system envisaged here is “definitely suitable for protecting farmland.”

At the same time, the interviews with SMEs have also flagged some areas for further consideration before development and adoption of the technology for Quelea control, as described below.

**Mission Fit**

Two of the four UAS SMEs expressed concern regarding the use of a sUAS to scare off a Quelea flock, considering the enormous sizes of their flocks. The third expert however noted that while the size of the Quelea flocks may pose a challenge, there are potential ways to address it. Specifically, he said that this
mission may require more than one UAS flying at the same time and the use of a larger and more robust platform.

A Quelea expert feared that the species may habituate to such a UAS platform quickly. In his own words he commented, “My feeling is that drones with bird-scaring noise broadcasts will work at a local scale but probably only in the short-term. Quelea will probably soon learn that they are non-lethal.”

However, a UAS expert explained that with sufficient diversification of Quelea distress and predator threat sounds, birds do not habituate to auditory stimulus:

Due to the threatening nature [of the sounds], they [the birds] leave the area unless they are protecting their young or there is a food source that is worth the threat. In that case, they don’t really habituate but some choose to ignore the threat.

Finally, it is important to note that even if UAS prove to be effective in scaring Queleas, it is unclear at this stage how far would flocks fly away. For example, as mentioned earlier, experiments with the GooseBuster showed that geese moved up to a 300 feet away from the device. Indeed, the GooseBuster is a stationary speaker system that is based solely on bioacoustics, and a UAS that combines both visual and auditory stimuli with an aerial mobility may be better for this task. However, it is important to note that pushing flocks away to a neighboring farm would not be a satisfactory solution unless all farms in one area are protected by UAS or other effective measures. Thus, to ensure no externalities are created for other farmers, policymakers may need to consider a whole community approach.

Safety

As noted earlier, there is a risk that UAS may crash as a result of an encounter with Quelea birds. In addition to the risk that a person, animal or something valuable would be hit by the UAS as it hits the ground, a UAS crash also poses a fire hazard. UAS are mostly powered by Lithium-Polymer batteries that are very sensitive to charging durations and use. The construction and composition of this type of batteries cause them to have a tendency to build up internal gasses that expand and eventually explode into a fire. This fire risk becomes more severe in the event of a UAS crash, especially if beyond LOS (hence extending the response time). Considering that Queleas roost near national parks and reserves, and that the capacity to put out fires in rural Africa may not be optimal make fire hazard a consideration that needs to be accounted for.

Technical Literacy Required for Operation

UAS require certain technical literacy, especially the larger ones. Thus, SMEs noted that in choosing the UAS that may be fit for the mission, it is important to have the operator in mind, referring specifically to two options—farmer or government operators. On the one hand, sUAS are simpler to use and can potentially be flown by farmers trained for this purpose. The advantage of this option is that farmers can deploy the UAS as soon as they detect an approaching Quelea flock, obviating the need to contact the government and wait for their arrival. In addition, sUAS may be more agile and maneuverable and more genuinely mimic the appearance of a predator. On the other hand, sUAS have other shortcomings (e.g.,
low endurance, fragile airframe) that may not render them fit for the mission. Larger platforms can have higher endurance and a more robust frame suitable for rural terrain however they need to be operated by professionals (presumably from the government), are more expensive and less resemble the Queelas’ natural predators.

Degree of Autonomy
Experts noted that for scaring birds away UAS can have varying degree of autonomy—from RC, controlled fully by an operator, to semi-autonomous for which GPS coordinates are entered in advance. The preferable option would be determined in experiments. Nevertheless there are a few issues for consideration. First, While RC is preferable usually from a regulatory perspective, its effectiveness is limited if the birds fly away and are out of LOS but the operator still wants to scare them away farther. A camera onboard the UAS can overcome this problem but it would require more power and would add complexity. A more autonomous control system may suffice if an experiment proves that a UAS flying around the field has a deterrent power and is able to scare birds away from afar even if it does not actually chase them. However, the more autonomous a UAS is, the less its flight behavior able to mimic that of a predator bird. In addition, it may not be legal.

Regulation
Three of the four UAS experts addressed the issue of regulation as a possible obstacle for UAS adoption for Quelea control. Existing bird control UAS are remotely-controlled and not automatic. The reason is that such systems are operated in the United States, Canada and other countries where regulations do not permit autonomous commercial UAS. According to one of the UAS experts, “In the United States the FAA does not permit such flights. Further, it requires that an operator be present, that operators go through training and that they obtain a certification from the FAA.”

One of the SMEs, who works in South Africa, where UAS regulations are now being finalized by the Civil Aviation Authority (CAA), stressed that for some UAS, the line of sight (LOS) requirement may necessitate operation of system by a licensed pilot. Alternatively, this expert said, “A UAS with D-GPS and video feedback options may obviate the need for a pilot but would still require a local operator accredited by the local government.”

This requirement however is for flights above 492 ft. (150 meters), whereas the assumption is that a bird-scaring platform may fly even at a lower altitude covering a small range of several acres at most.

On the other hand, the fourth UAS SME said that the legal void on aviation matters in Africa creates an opportunity for trying this technology in a non-regulated environment.

Possible Cultural Objection
while SMEs did not foresee resistance to UAS technology on the part of farmers, they did note the importance of being aware of cultural issues, as one expert put it: “I see no reason why they [UAS] shouldn’t be accepted but beware of strange beliefs in some places, so always ask the locals for permission! You may also need government approval to fly them.”
Conclusion

In conclusion, interviews with SMEs supplemented the literature and established an initial match between the requirements posed by the Quelea problem and the specs of UAS technology as a protective (and to extent as preventative) control measure. At the same time, they illuminated some important technical challenges associated with the potential use of UAS in such missions. Further, they flagged some non-technical issues which may hinder the adoption of this technology, in particular safety risk, operational issues, regulation and cultural sensitivities. To further examine the feasibility of employing UAS for Quelea control on non-technical grounds, a field study was carried out in Kenya.

4.6 Field Study: Methods

Following extensive background research supplemented by insights from SMEs that helped illuminate the Quelea problem and identify the key technical requirements of a potential UAS solution, rich survey and interview data were collected from various stakeholders and key informants along the sorghum and millet crops value chain in Kenya. The focus on sorghum and millet stems from the fact that those are the Queleas’ favorite foods and hence individuals and organization along this value chain are most vulnerable to this threat. Moreover, these two small grain crops are considered not only nutritious but also especially suitable for the arid and semi-arid climate in Sub-Saharan Africa and any factor that reduces their yield in turn undermines food security. 

The open-ended questions included in both methodologies encouraged respondents to describe in detail, using their own words, their unique perspectives on the Quelea problem, currently-used methods and their perceptions on potential drivers and barriers to adoption of UAS technology for this purpose. This approach seems most appropriate for such an exploratory research that examines the feasibility of developing and adopting an innovative technological application for a longstanding, yet often overlooked, dire problem in the most underprivileged regions of the world.

This section describes the data collection approaches used in this chapter. These methods include a survey of smallholder farmers and in-depth semi-structured interviews with different crop grain production stakeholders in Kenya. Each method helped elicit detailed information pertaining to the magnitude of the Quelea challenge, its impact on farmers’ food security and livelihood, farmers’ coping strategies, perceptions vis-à-vis the employment of UAS in Quelea control and possible drivers and barriers to adoption of the technology for this purpose.

4.6.1 Survey Methodology

Survey Instrument

The survey of smallholder farmers in Kenya included both close and open-ended questions that encouraged farmers to describe in their own words their experiences and perceptions. In addition to collecting farmers’ demographic characteristics and information about their farming experiences, the survey covered the following topics:
• The magnitude of the Quelea problem;
• The associated economic losses attributed to this problem;
• Currently used means to mitigate it;
• Perspectives regarding the use of lethal methods—spraying roosts or breeding colonies with chemicals; or trapping the Queleas and eating them.
• Perceptions vis-à-vis the use of innovative pest management techniques with emphasis on UAS technology.

The detailed survey questions and analysis methods are attached as Appendix D. These questions were drafted by study’s author after consultation with UAS and Quelea SMEs. The survey was shared with leaders of the East Africa Sorghum Value Chain Project at the European Cooperative for Rural Development (EUCORD) project, an NGO operating in Kenya which was sub-contracted to field the survey. EUCORD officers reviewed the questions and pre-tested the survey to ensure that the questions were clear, comprehensive and used appropriate terminology that could be translated into the local language Swahili. EUCORD officers reviewed the questions and provided feedback. Except for minimal adjustments, the reviewers did not change any of the questions.

Survey Sample and Delivery
To overcome the logistic hurdles involved in fielding a non-electronic survey remotely from the United States, the organization EUCORD was sub-contracted to field the survey. Officers at the East Africa Sorghum Value Chain Project, who are experienced in fielding surveys in Kenya and in East Africa in general, and who are working regularly with millet and sorghum farmers who are affected by the Queleas, located farmers for the survey. A convenience sampling design was used.

Comprised of five trained enumerators and two supervisors, the EUCORD team requested heads of farmer associations to offer participation to farmers that met the following criteria:

• Have been a farmer in the last three years at least;
• Have grown sorghum and/or millet; and
• Have experienced the Quelea menace and have attempted to control it.

Potential respondents were contacted in advance either directly or through heads of farmer schemes tasked with organizing farmer groups in the area. While initially the study team had planned to fill out the survey at farmers’ homes, due to logistical constraints, respondents were invited instead to a common gathering site. There, the study team briefly explained the purpose of the study and asked to answer all questions honestly and accurately. In addition, at each gathering the study team surveyed the group of whether they know what a UAS, UAVs or drones are. Surprisingly, only three farmers had heard of this technology previously. Therefore, prior to administering the survey, the team explained to the farmer groups collectively what UAS are.

For their participation, they were promised KES 200 (equivalent to USD 2) as reimbursement for their travel expenses, a loaf of bread and a bottle of soda at the end of the survey. However, farmers said in person that their main motivation to participate in the study was its focus on the Quelea menace and the prospect of finding a solution to one of their gravest challenges to agricultural production. According
to heads of farmer schemes, participation amongst invitees was close to 100 percent with a few exceptions of farmers that could not travel. The survey was conducted in person in English and when necessary, EUCORD agents translated responses from Swahili into English. Survey results were reported back in English. To ensure the quality of the data collected and the integrity of the collection process, EUCORD followed the next steps:

1. The five enumerators and two supervisors were trained on basic data quality measures (accurate logging of responses, safeguarding personal data, etc.). Supervisors ensured data quality was maintained by the enumerators.
2. The enumerators’ and supervisors’ employment contract stated that they are responsible for data quality and that their payment is conditional on performance.
3. Data entry by the study team (enumerators and supervisors) was done under close supervision of EUCORD agents.

Survey Respondents
A total of 107 smallholder farmers in five rural counties in East Kenya met the aforementioned criteria. The EUROCORD team ensured that at least 20 farmers were selected from each county. Table 4.3 lists the sample sizes of farmers by county. Figure 4.4 graphically depicts the percentage each county represents in survey respondents.

<table>
<thead>
<tr>
<th>County</th>
<th>Sub-County</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embu County</td>
<td>Mbeere South</td>
<td>20</td>
</tr>
<tr>
<td>Tharaka Nithi County</td>
<td>Tharaka North</td>
<td>19</td>
</tr>
<tr>
<td>Kitui County</td>
<td>Kitui Central</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Mwingi Central</td>
<td>17</td>
</tr>
<tr>
<td>Makueni County</td>
<td>Makueni</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Kibwezi East</td>
<td>3</td>
</tr>
<tr>
<td>Meru County</td>
<td>Buuri</td>
<td>17</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>107</strong></td>
</tr>
</tbody>
</table>
These counties were not selected randomly. Rather, they are known as areas affected by the Queleas regularly mostly because of their proximity to national parks where Quelea flocks roost. For example, the sub-county Kibwezi West is extremely vulnerable to Quelea attacks due to its location nearby the Tsavo National Park. Figure 4.5 shows the location of these counties on Kenya’s map.

The respondents represent a mixed group. Accordingly, the ranges of their characteristics—age groups, experience in farming, crop types, and familiarity experiences with Quelea damage—are quite large. This is a product of the small convenience sampling design which sought to include different types of farmers in five different counties. While this attribute of the sample can challenge any attempt to infer specific relationships between farmers’ perceptions and their characteristics, the representation of different geographical locations in Kenya, various plot sizes and crop types, and diverse set of farming
experiences provides useful insight into the magnitude of the problem and perceptions regarding the proposed solution.

As shown in Table 4.4, of the 107 respondents, 31.8 percent (34) are male farmers and 68.2% (73) are female. The vast majority of farmers (75, or 70.1 percent) were older than 40 year old. Twenty two (or 20.6 percent) are between the ages 51–60 and 20 farmers (or 18.7 percent) are over the age of 61. Only six farmers are between the ages of 21 and 30 (5.6 percent). Even though this convenience sample may not be representative of all Kenyan farmers, the contrast between the numbers of older (over 50) and younger farmers is illuminating and supports observations made by farmers in interviews according to which the Kenyan farmer population is aging. This is especially illuminating given the age composition of the total Kenyan population of which 41.5 percent are under the age of 15; 18.7 percent are 15–24 years old; 33 percent are 25–54; and only 6.6 percent are over the age of 55—3.8 percent are 55–64 years old and 2.8 percent are 65 and over. The average life expectancy at birth in Kenya is 61.1 years.

<table>
<thead>
<tr>
<th>Table 4.4 Survey Respondent Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristics</strong></td>
</tr>
<tr>
<td>Gender</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>21–30</td>
</tr>
<tr>
<td>31–40</td>
</tr>
<tr>
<td>41–50</td>
</tr>
<tr>
<td>51–60</td>
</tr>
<tr>
<td>Over 60</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Farmers had a wide range of farming experiences. On average, respondents have been farmers for 23 years with a standard deviation of 13.41 years. Of the 105 farmers that responded to this question, 102 (98 percent) belonged to a farmer group or association. On average, groups consisted of 26 farmers with a standard deviation of 12.58. The minimal number of farmers in a group was five whereas the maximum was 120. Farmer plots reported ranged from one to 26 acres. On average, plot size was five acres with a standard deviation of 4.42 (Figure 4.6).
Farmers tended to diversify their crops and on average grew 3.49 types of crops. The main crops grown by survey respondents are white sorghum, maize, millet, green grams, cowpeas and beans, as indicated in Table 4.5. Indeed, the focus of this study was on farmers growing sorghum and millet and these crops are typical in Eastern Kenya. Nevertheless, had the survey been fielded in Central Kenya or the West side of the country, the crop breakdown would have likely been different. For example, rice is the third most important staple food in Kenya after maize and wheat. While most rice is imported, some farmer schemes in counties in other regions predominantly grow this crop. Rice farmers however also suffer from Quelea attacks in Kenya, and in other countries, and therefore may experience similar hardships as sorghum and millet farmers.

Thus, even though the survey is not representative of the full population of interest - smallholder farmers in Sub-Saharan Africa, it is a first attempt at capturing farmers’ perspectives on the Quelea problem, shortcomings of existing deterrence methods, and the proposed UAS solution.
Table 4.5 Main Crops Grown

<table>
<thead>
<tr>
<th>Crop Type</th>
<th>N</th>
<th>Percent*</th>
</tr>
</thead>
<tbody>
<tr>
<td>White sorghum</td>
<td>103</td>
<td>96.3%</td>
</tr>
<tr>
<td>Maize</td>
<td>92</td>
<td>86%</td>
</tr>
<tr>
<td>Millet</td>
<td>61</td>
<td>57%</td>
</tr>
<tr>
<td>Green grams</td>
<td>61</td>
<td>57%</td>
</tr>
<tr>
<td>Cowpeas</td>
<td>60</td>
<td>56.1%</td>
</tr>
<tr>
<td>Beans</td>
<td>50</td>
<td>46.7%</td>
</tr>
<tr>
<td>Red sorghum</td>
<td>31</td>
<td>29%</td>
</tr>
<tr>
<td>Pigeon peas</td>
<td>22</td>
<td>20.6%</td>
</tr>
</tbody>
</table>

* The survey allowed farmers to select more than one crop type thus the percentages do not add to 100.

Analysis of Survey Data

The responses to the survey’s close-ended questions were entered directly into a computerized survey system. The responses to the open-ended questions were typed by the enumerators within a few hours after the survey was completed (the EUCORD team had to leave the rural sites first to connect to a computer and record all data).

The data from the close-ended questions were analyzed using conventional statistical methods. The data from the open-ended questions were reviewed and analyzed for themes. These data in turn were supplemented by qualitative data obtained through in-depth interviews with similar famers as well as other key informants in small crop grain production in Kenya and in Africa more generally.

4.6.2 Interview Methodology

Interview Approach

Additional information was collected through in-depth interviews with stakeholders and key informants along the sorghum and millet crops value chain in Kenya. These interviewees represented three populations:

1. Smallholder sorghum and millet farmers in Kenya regularly affected by the Quelea problem (different farmers from those surveyed).
2. NGOs and international organization assisting grain crop smallholder farmers;
3. Kenyan Government officials in the area of small crop grain production, processing and packaging; and others tasked with either Quelea-control or aviation regulation.

The interviews were conducted using a semi-structured protocol (Appendix E). This methodology provided a consistent approach to data collection across respondents from the same population and ensured that all topics of interest were covered. At the same time, it was flexible enough to allow respondents to describe their perspectives in length and offer new insight not addressed in the questions.
Interviews with smallholder farmers covered similar topics to those examined in the survey, including the Quelea problem; its impact on farmers’ livelihoods, their coping mechanisms, perspectives on the use of lethal preventative bird control measures and perceptions regarding the use of UAS in such missions. Interviews with NGO staff and government officials also asked about potential drivers and barriers to adoption of UAS technology for Quelea control (cost, regulation, and so forth) as well as implementation models.

All interviews were held in English. With the exception of one interview with a government official that was began over the phone and continued over email, all interviews took place in person. The number of participants in each interview ranged from one to ten. Interviews lasted between one and two hours, depending on the number of participants. All respondents were promised confidentiality. Even though the interviews were not recorded, accurate notes were taken and reviewed immediately after the interviews. If anything was unclear or missing, interviewees were asked to clarify or supplement the information.

Interview Samples
The sample of key informants of the three population types was developed purposively and may not be representative of all stakeholders affected and involved in addressing the Quelea problem in Africa. Notwithstanding the limitations of the sampling design, the sample represents different geographical locations in Kenya, various roles along the sorghum and millet crop production value chain, and key informants on the problem and the proposed solution.

**Population 1: Smallholder Farmers**
The first population of smallholder farmers was selected as a complement to the more structured survey. Farmers were interviewed in various locations in Kenya with the objective of observing the environment in which they live and operate and to gain a deeper knowledge of their situation as expressed in their own words.

This sample consisted of 52 smallholder farmers in five counties in rural areas of Kenya: Embu, Tharaka Nthi, Makuenei, Homabay, and Nairobi (map in Figure 4.7). Most farmers were from Embu and Tharaka Nthi as shown in Table 4.6. Again, farmers were compensated for their time and effort in responding to the survey with KES 200 travel expense reimbursement, a loaf of bread and soda. Similarly to the farmers surveyed more formally, most farmers interviewed expressed gratitude for the study’s effort to tackle the Quelea problem and said that was their prime motivation to take part in it.
Figure 4.7 Map of Site Visits and Interviews in Kenya

Table 4.6 Smallholder Farmer Interview Sample by County

<table>
<thead>
<tr>
<th>County</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embu</td>
<td>20</td>
</tr>
<tr>
<td>Tharaka Nthi</td>
<td>15</td>
</tr>
<tr>
<td>Makueni</td>
<td>6</td>
</tr>
<tr>
<td>Homa Bay</td>
<td>9</td>
</tr>
<tr>
<td>Nairobi</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>52</td>
</tr>
</tbody>
</table>

In contrast to the farmers surveyed, most interviewee, 41 (or 79 percent), were male farmers whereas only 11 (or 21 percent) were females. Their plot sizes ranged from one to 100 acre with an average of 4–
5 acres. All interview participants were members of farmer groups, and all grow millet and sorghum although many of them have diversified their crops and started growing maize due to the vulnerability of sorghum and millet to Quelea attacks.

Again, this sample design was of convenience. The EUCORD team helped set up interviews with all the farmers in Embu, Tharaka Nthi and Makueni. There was no restriction this time on interviewees’ levels of farming experience however they had to meet the following criteria:

- Have been sorghum and/or millet farmers;
- Have experienced the Quelea menace and have attempted to control it.

Here also, potential respondents were contacted in advance through heads of farmer groups (hence they all belong to associations). Due again to logistical hurdles, interview participants met the study team in a common site where the study’s objectives were explained to the group. Only one farmer in Makueni knew what a “drone” is (he referred to Kenya’s fight with the terrorist group Al-Shabaab that allegedly uses military drones near the border with Somalia). Therefore, a short introduction of this technology was provided.

Interview participants in the county of Homabay were invited by government officials working in the area of small crop grain production. Interviewees in Nairobi were identified by a senior member of the African Center for Economic Transformation who seeks to improve agricultural value chains across Africa and who is interested in exploring the use of UAS for Quelea control.

All farmer interviews were conducted in person in English. Twelve out of the 52 farmers were not fluent in English hence interviews were held in Swahili with local advisors (from EUCORD and ACET) translating into English simultaneously.

Population 2: NGO Representatives

The site visits to farmlands indicated that farmers on their own are not likely to afford and operate and maintain UAS technology effectively. The reasons for this inference are threefold. In general, Kenyan smallholder farmers are poor and most live in areas with no power. Further, for the most part, they are not technically savvy—only one of the farmers interviewed had a tractor for instance. Smallholder farmers are assisted frequently by NGOs, which provide them with seeds, training, farming inputs, access to credit and so forth. Therefore, to examine the feasibility of adopting UAS for Quelea control this study reached out to representatives of several NGOs that work in Kenya and assist, among other activities, to sorghum and millet farmers. The assumption was that NGOs may provide insight on drivers and barriers to adoption of such technology for this mission.

Overall, 14 representatives of NGOs were interviewed. These NGOs promote sorghum and millet production among smallholder farmers in Kenya and in other countries in East Africa (Ethiopia, Uganda and Tanzania). This sample was of convenience and selected based on professional relationships between researchers at ACET and NGOs promoting improvement in small grain production value chains. All interviews took place in the city (and the county) of Nairobi and were conducted in person in English.
Detailed notes were taken during the interviews and their content was confirmed by the participants themselves or an accompanying staff from EUCORD, ACET or the Kenyan government.

**Population 3: Government and Intergovernmental Organization Officials**

The operation of commercial UAS requires government approval (through regulation) and potentially support (financial). Therefore, it was important to gain insight from officials in the fields of agriculture, pest management and aviation. Overall, five Kenyan government officials were interviewed, two of whom directly support smallholder farmers in Western Kenya in production and distribution of sorghum and millet as well as other grain crops. Another official is a senior government researcher in the area of millet and sorghum whereas the fourth government interviewee is an official tasked with aviation regulation. The last Kenyan government official interviewed is tasked with crop protection, including pest management under which also falls the responsibility for Quelea control.

Two additional participants are officials with an intergovernmental body, which was founded under the auspices of the UN and which connects African governments on agricultural issues.

The sample design was again of convenience. Officials were contacted via personal and professional relationships through ACET and RAND. All but one interview took place in person in Nairobi and in Kakamega (Figure 4.7). The interview with the pest management official was conducted over the phone and via email. All interviews were held in English and detailed notes were taken.

**Analysis of Interview Notes**

The notes from the interviews were typed within several hours after the completion of interviews (the several hours gap was inevitable considering the distances between rural farming sites not connected to power grids and more developed settings that allowed for continuous use of a computer). The qualitative data from the interviews were analyzed for themes across the key topics explored; including description of the Quelea problem and its effects, currently used methods to address it, perspectives regarding lethal preventive methods, perceptions on the employment of UAS for such purpose, and potential barriers and drivers that may influence the adoption of this technology.

The qualitative approach employed helped tie together knowledge of different stakeholders to gain comprehensive understanding of how the Quelea problem affects the small crop grain value chain in Kenya. Further, it has yielded detailed information about issues that were covered more curtly in the survey as well as entirely different issues including for instance regulation and political considerations.

**4.7 Results**

This section presents the combined results from the smallholder sorghum and millet farmer survey and the interviews with farmers, NGO personnel and government officials. The results are reported according to the key issues explored in both methods as well as the main themes reflected in the qualitative data. Where appropriate, results are supported by direct quotations that illustrate observations collected through open-ended survey questions and/or interviews.
**The Quelea Problem**

Theme 1: Field Study Confirmed the Magnitude of the Quelea Challenge

Both the survey and interview data confirmed the magnitude of the Quelea challenge. Eighty four of the 107 farmers surveyed said that the Quelea is their number one challenge to crop production, accounting for 78.5 percent of responses (Table 4.7). Only drought was ranked higher by a larger number of respondents (93, or 86.9 percent). Drought indeed is a major impediment to farming in Eastern Kenya. However, the timing of the survey may explain why drought was cited by more farmers than the Queleas. The survey was fielded in March 2015, a period culminating a prolonged drought. On the other hand, the last time the Queleas attacked these farmers was in November the previous year. Therefore, it is plausible that farmers were less concerned at the time of the study about a future Quelea attack while struggling with severe drought.

<table>
<thead>
<tr>
<th>Crop Type</th>
<th>N</th>
<th>Percent*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>93</td>
<td>86.9%</td>
</tr>
<tr>
<td>Quelea</td>
<td>84</td>
<td>78.5%</td>
</tr>
<tr>
<td>Input shortage</td>
<td>38</td>
<td>35.5%</td>
</tr>
<tr>
<td>Other bird pests</td>
<td>24</td>
<td>22.4%</td>
</tr>
<tr>
<td>Non-bird pests</td>
<td>24</td>
<td>22.4%</td>
</tr>
<tr>
<td>Other weather phenomenon</td>
<td>13</td>
<td>12.1%</td>
</tr>
<tr>
<td>Low demand</td>
<td>10</td>
<td>9.3%</td>
</tr>
</tbody>
</table>

*The survey allowed farmers to select more than one challenge thus the percentages do not add to 100.

A head of a farmer scheme interviewed said that the Queleas are usually ranked number one as an obstacle for farming despite the drought:

> We did baseline surveys in 2013 and 2015 and asked farmers what the biggest challenge to sorghum growing is. They said the bird was the number one challenge with the drought being number two. The reason is that even with 300 ml of rain distributed we can get a crop. That is why sorghum is better than millet—it is more drought-resistant. But when the bird attacks, nothing is left. When they come, you are left with nothing. They “harvest” five acres in half an hour. So what’s the point in planting to begin with? Farmers are not fools.

An NGO representative working in Kenya confirmed that often Queleas are considered as the gravest challenge to small grain crop production:

> The losses attributed to the bird are mostly in sorghum and mostly affect smallholder farmers. Birds are also the main problem in Uganda and Tanzania. In a survey we did in Tanzania the Quelea was raised as the number one
challenge that farmers face in growing sorghum. The bird poses even a greater problem in Ethiopia with birds and in Sudan also with Sorghum and millet. This is a big problem that extends far beyond Kenya.

While other pest birds were cited as a challenge, one of the farmers in Makueni County said that the scale of the problem is remarkably different. Superficially: “Local birds eat some sorghum also but they come in small numbers so don’t pose a problem. It is the Queleas that pose the gravest challenge.”

There was no statistically significant difference between female and male farmers’ reporting of the Quelea bird as one of the biggest obstacles to crop production (p-value > 0.1). Similarly, the variation in responses by plot size was not statistically significant either. On the other hand, responses did vary by age group at a significance level of p-value < 0.05. As Table 4.8 indicates, Quelea is considered more of a challenge among the youngest (21–30 year of ages) and oldest farmers (over 51) but less among the middle-aged group.

Table 4.8 Cross-Tabulation of Responses Regarding Quelea as a Challenge, by Age

<table>
<thead>
<tr>
<th>Response</th>
<th>21–30</th>
<th>31–40</th>
<th>41–50</th>
<th>51–60</th>
<th>Over 60</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quelea Challenge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>100%</td>
<td>76.9%</td>
<td>60.6%</td>
<td>90.9%</td>
<td>90.0%</td>
<td>78.5%</td>
</tr>
<tr>
<td>No</td>
<td>23.1%</td>
<td>39.4%</td>
<td>9.1%</td>
<td>10.0%</td>
<td>21.5%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>N</td>
<td>6</td>
<td>26</td>
<td>33</td>
<td>22</td>
<td>20</td>
<td>107</td>
</tr>
</tbody>
</table>

Farmers surveyed and interviewed provided graphic description of the size and impact of Quelea flocks, for example: “The birds come in huge swarms of 100,000 birds or even more.” “The birds make a huge plane-like sound forming a shade as they move in millions.” “At first the birds sent scouts to survey for food, once the scouts find suitable grain for them, the whole swarm of birds comes in the following day to attack the crops.”

Theme 2: Queleas Attack at Different Times in Different Places

Although some 20 percent of the farmers surveyed did not consider the Queleas as a major obstacle, all farmers have been previously attacked by these birds (Table 4.9).
Table 4.9 Frequency of Quelea Attacks

<table>
<thead>
<tr>
<th>Number of Times Attacked by Queleas</th>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only Once</td>
<td>5</td>
<td>4.7</td>
</tr>
<tr>
<td>2–3 times</td>
<td>21</td>
<td>19.6</td>
</tr>
<tr>
<td>4–10 times</td>
<td>8</td>
<td>7.5</td>
</tr>
<tr>
<td>11–20 times</td>
<td>2</td>
<td>1.9</td>
</tr>
<tr>
<td>Regularly (almost every season)</td>
<td>71</td>
<td>66.4</td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>100.0</td>
</tr>
</tbody>
</table>

As indicated in Table 4.9, 71 of the farmers surveyed (66.4 percent) suffer from Quelea attacks on a regular basis. Farmers indicated that most often the Queleas attack twice per year for approximately six weeks, depending on the region. Most farmers, whose plots are attacked regularly, said that attacks normally place during the months of March–April and November–December, followed by May–June (Table 4.10).

Table 4.10 Months of Quelea Attacks

<table>
<thead>
<tr>
<th>Months Attacked by Quelea</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Jan to Feb</td>
<td>18</td>
</tr>
<tr>
<td>Mar to Apr</td>
<td>40</td>
</tr>
<tr>
<td>May to June</td>
<td>31</td>
</tr>
<tr>
<td>July to Aug</td>
<td>11</td>
</tr>
<tr>
<td>Sep to Oct</td>
<td>5</td>
</tr>
<tr>
<td>Nov to Dec</td>
<td>38</td>
</tr>
</tbody>
</table>

* Farmers were given multiple options to select from thus percentages do not add up to 100.

One of the challenges with handling the Quelea threat stems from its unpredictable nature. While on average they show up during the aforementioned months, sometimes they appear earlier or later in the crop life cycle. As one farmer explained:

Last year they came in February–March and harvested crops that were planted on November–December. We harvested again in May–June but that time the birds were not around. They come most seasons but not as much in others. The problem is that we cannot know in advance when they will come and when they won’t.
Theme 3: Queleas Prefer Some Crops to Others

Part of the reason that farmers diversify their crops is that some grains are more vulnerable to Quelea attacks than others. For example, maize is protected partially by the husk. One hundred and six farmers responded to a question on which crops are preferred by the Queleas (Table 4.11). The vast majority (104, or 98.1 percent) cited white sorghum, followed by millet (64, or 60.4 percent), green grams (37, 34.9 percent), red sorghum (27, or 25.5 percent), and maize (25, or 23.6 percent).

<table>
<thead>
<tr>
<th>Crops Preferred and Damaged by Quelea</th>
<th>Responses</th>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Sorghum</td>
<td></td>
<td>104</td>
<td>98.1%</td>
</tr>
<tr>
<td>Millet</td>
<td></td>
<td>64</td>
<td>60.4%</td>
</tr>
<tr>
<td>Green Grams</td>
<td></td>
<td>37</td>
<td>34.9%</td>
</tr>
<tr>
<td>Red Sorghum</td>
<td></td>
<td>27</td>
<td>25.5%</td>
</tr>
<tr>
<td>Maize</td>
<td></td>
<td>25</td>
<td>23.6%</td>
</tr>
<tr>
<td>Cowpea</td>
<td></td>
<td>21</td>
<td>19.8%</td>
</tr>
</tbody>
</table>

* Farmers were given multiple options to select from thus percentages do not add up to 100.

Sorghum farmers reflected on the Queleas’ preference for this crop as illustrated by quotations from two farmers interviewed in the Tharaka Nithi County:

When the sorghum matures its color is white-gray. When it is harvested by the birds it looks reddish because the white-gray part is gone. A field after a bird attack is all red.

We also grow red sorghum because the birds don’t like it as much as the white one but it is also less favorable for human consumption and less nutritious so we can sell less of it. Also, when there is only the red sorghum around, they will still eat it so that is not a solution.

Heads of farmer schemes said that crop diversification does not always work. For instance:

When farmers grew drought-resistant sorghum varieties and those were eaten by the birds they came to us to find a solution. They all planted red sorghum afterward, flooded the market with it but there was not enough demand. They started shifting toward the white sorghum again but it is sweeter and the birds like it and eat it all. People here say they will stop entirely with the white sorghum but that is the marketable variety.

It is important to note that had the survey taken place in other areas, where more rice and wheat are grown (and less sorghum and millet), farmers would have likely reported different crop vulnerability, as
confirmed by an NGO representative supporting farmers: “The bird is the biggest problem when it comes to sorghum but it also affects millet, rice and wheat.”

Two farmers in Homa Bay County shared their experiences with non-sorghum crops:

We are by the lake [Lake Victoria] which means we are affected by the birds significantly. The lake helps the birds. I have five acres and grow cotton, rice, soy bean, sorghum and millet—one acre for each crop. Birds like sorghum most and second best is millet but they also eat rice and wheat.

I thought about stop growing rice because of the bird. There are varieties of sorghum that the bird does not like but they like all rice types. It depends on income. If the crop brings more money I will continue to grow it and chase the birds but if not, I will stop.

We grow a lot of millet and sorghum here. We used to grow red sorghum and the bird would eat that as well. In 2009 switched to white sorghum because there is a market for it.

The government official tasked with pest management provided more detail on the timing and geographical distribution of Quelea damages as well as on the types of crops affected. According to him:

The damage is distributed as follows—the counties of Siaya and Busia that grow rice are affected throughout the year. The Narok, Nakuru Nyandarua and Meru counties that grow wheat are affected from June to February. In Kirinyaga County, where rice is grown, the birds attack between July and October. Rice is also grown in the Tana River County which is usually affected in January–February. The counties of Machakos, Kitui, Makueni and Tharaka, growing mostly sorghum and millets, are also hurt during January and February.

Quelea Impact on Farmers’ Livelihoods

Theme 4: Quelea Attacks Inflict Severe Damage to Crops

On average, farmers surveyed reported a 59.72 percent loss of crops in the event of Quelea attacks. The range of losses is wide as indicated by the 22.86 standard deviation. Of the 106 farmers who responded to this question, 33 (31.1 percent) reported a 50 percent loss; 20 farmers (18.9 percent) reported an 80 percent loss, and an equal number (10, or 9.4 percent) reported 40 and 100 percent losses (Figure 4.8).
Government officials interviewed said that losses vary tremendously and reach 100 percent but that there is no data documenting this issue. While there was no statistically significant difference between the average crop loss reported and gender, age group and farm size, some of these results are still worth illuminating. For example, as indicated in Table 4.12, farmers over the age of 51 reported on average higher percentage crop losses than younger peers. That may be explained by the difficulty of older farmers to protect their crops effectively given the little available means at their disposal.

Table 4.12 Average Crop Percentage Loss reported, by Farmer Age Group

<table>
<thead>
<tr>
<th>Farmer Age Group</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>21–30</td>
<td>6</td>
<td>53.33</td>
<td>8.165</td>
</tr>
<tr>
<td>31–40</td>
<td>26</td>
<td>51.92</td>
<td>21.170</td>
</tr>
<tr>
<td>41–50</td>
<td>33</td>
<td>60.00</td>
<td>22.776</td>
</tr>
<tr>
<td>51–60</td>
<td>21</td>
<td>66.19</td>
<td>28.368</td>
</tr>
<tr>
<td>Over 60</td>
<td>20</td>
<td>64.50</td>
<td>19.861</td>
</tr>
<tr>
<td>Total</td>
<td>106</td>
<td>59.72</td>
<td>22.864</td>
</tr>
</tbody>
</table>

Farmers were eager to describe the damages inflicted by the Queleas either in response to open-ended survey questions or in interviews. Some examples include: “The birds came in thousands to my farm and ate my sorghum and millet in 15 minutes.” “They destroy even the grass that is fodder for our animals.” “I went to take a beer and left my farm unkempt, on returning they had eaten everything.”
NGO staff emphasized the threats the Queleas pose to farmers, for instance: “Quelea birds are a threat to farmers and their household livelihoods and food security.” “Because of their crop damage, they discourage farmers in planting crops suitable to their agro-ecological zones.”

**Farmers’ Coping Mechanisms with the Quelea Challenge**

**Theme 5: Currently-Used Quelea Control Methods Are Varied and Limited in Their Effectiveness**

Responding to the survey question on which methods they use for Quelea-control, farmers, 87 out of 106 farmers (82 percent) reported that they throw stones at the birds, either by hand or by using catapults and slingshots (or all three), 69 farmers (65 percent) said they were producing loud sounds, either by their own voice or an instrument (clapping, tin cans, and so forth). Another 25 (23.5 percent) have in place the aforementioned system of polls and iron sheets. Chasing the birds was reported by 18 respondents (16.9 percent), and planting other crops that draw the birds was mentioned by 13 farmers (12.2%). Fifteen farmers (14.1 percent) use other methods that include calling the Crop Protection Unit to eradicate the Queleas using chemicals, positioning scare crows on their farms, using nylon papers, trapping them with sticky plant syrup, or simply designating an area on the farm that they can eat and protecting the rest of the crops (Table 4.13).

<table>
<thead>
<tr>
<th>Methods Used for Quelea Control as Reported by Farmers</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise made by human or by a tool</td>
<td>69</td>
</tr>
<tr>
<td>Throwing stones with or without catapults/slingshots</td>
<td>87</td>
</tr>
<tr>
<td>Chasing the birds by foot</td>
<td>18</td>
</tr>
<tr>
<td>Special designed system with iron sheets</td>
<td>25</td>
</tr>
<tr>
<td>Plant trap crops</td>
<td>13</td>
</tr>
<tr>
<td>Use of other methods</td>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>69</td>
<td>65%</td>
</tr>
<tr>
<td>87</td>
<td>82%</td>
</tr>
<tr>
<td>18</td>
<td>16.9%</td>
</tr>
<tr>
<td>25</td>
<td>23.5%</td>
</tr>
<tr>
<td>13</td>
<td>12.2%</td>
</tr>
<tr>
<td>15</td>
<td>14.1%</td>
</tr>
</tbody>
</table>

On average, respondents to the survey reported that they use 2.14 Methods of Quelea control, with a standard deviation of 1.108. The minimal number of methods reported was one with the maximal being five (Table 4.14).
Table 4.14 Descriptive Statistics on Number of Control Methods Used by Farmers

<table>
<thead>
<tr>
<th>Number of Method Used</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35</td>
<td>33.0</td>
</tr>
<tr>
<td>2</td>
<td>38</td>
<td>35.8</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>20.8</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>4.7</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>5.7</td>
</tr>
<tr>
<td>Total</td>
<td>106</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Mean: 2.14
Std. Deviation: 1.108

As emphasized by both farmers surveyed and interviewed, none of the methods is cost-effective. Referring to the most common approach of making noise and throwing stones at the birds to make them fly away, farmers said:

We throw stones at them, make noise, use slingshots. All of the neighbors do the same. Some shout but with a slingshot you can cover a larger area than with your voice or noise. Sometimes we also use magnetic strips that reflect the sun light. This works for a bit but the birds get used to it.

I have six acres. I plant half sorghum and half miller. It is very hard to protect the crops because I need to run around and chase the birds. When I am protecting one side of the field the birds attack the other. I can’t afford to buy the string [referring to iron sheets] because it is very expensive.

Three farmers interviewed said that being around a flock of Queleas is not only frustrating but also scary:

It is scary to be around the birds. There are no recorded incidents of attacks of birds on people because people just run away from them. When these birds sit on a tree branch, it breaks because their cumulative weight is so heavy.

Breaking down the methods used by age group (Table 4.15) indicates that there are no meaningful differences between the methods farmers in different ages use. Farmers of all ages mostly scare Quelea birds by sounds and throwing stones. Higher proportion of farmers of ages 31–40 use the iron sheet system—nine out 52 farmers accounting for 17 percent of this age group. Interestingly, a larger share of older farmers of 51–60 year of age (seven farmers or 15 percent) chase the birds running.
Table 4.15 Methods used by age group

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>No. Made by Human or by a Tool</th>
<th>Throwing Stones with or Without Catapult or Slingshot</th>
<th>Chasing by Running</th>
<th>Special System with Iron Sheets</th>
<th>Plant Trap Crops</th>
<th>Use of Other Methods</th>
<th>Number of Farmers in Age Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>21–30</td>
<td>3 (21%)</td>
<td>6 (43%)</td>
<td>1 (7%)</td>
<td>1 (7%)</td>
<td>2 (14%)</td>
<td>1 (7%)</td>
<td>14 (100%)</td>
</tr>
<tr>
<td>31–40</td>
<td>16 (31%)</td>
<td>19 (37%)</td>
<td>3 (6%)</td>
<td>9 (17%)</td>
<td>2 (4%)</td>
<td>3 (6%)</td>
<td>52 (100%)</td>
</tr>
<tr>
<td>41–50</td>
<td>20 (29%)</td>
<td>27 (39%)</td>
<td>6 (9%)</td>
<td>8 (11%)</td>
<td>2 (3%)</td>
<td>7 (10%)</td>
<td>70 (100%)</td>
</tr>
<tr>
<td>51–60</td>
<td>13 (28%)</td>
<td>17 (36%)</td>
<td>7 (15%)</td>
<td>5 (11%)</td>
<td>4 (9%)</td>
<td>1 (2%)</td>
<td>47 (100%)</td>
</tr>
<tr>
<td>+60</td>
<td>17 (39%)</td>
<td>18 (41%)</td>
<td>1 (2%)</td>
<td>2 (5%)</td>
<td>3 (7%)</td>
<td>3 (7%)</td>
<td>44 (100%)</td>
</tr>
<tr>
<td></td>
<td>69</td>
<td>87</td>
<td>18</td>
<td>25</td>
<td>13</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

Farmers mentioned also that scarecrows often do not work:

We use scarecrows to scare the birds. It is tedious work and there is not enough labor. People are not willing to shout all day long. And we can’t kill the birds they roost in or near national parks, rivers or lakes. We just need to find better means of scaring them.

Only two farmers mentioned calling for the government’s help, referring specifically to the Crop Protection Unit. Both expressed frustration and said that they feel “alone” in their battle against the Queleas:

When the birds attack and we locate their roosts, we report to Nairobi to the Crop Protection Unit which can organize spraying of roots. But—it can take them up to a full month until they show up because they only have one airplane and use it not only all over Kenya but also in Tanzania.

Quelea also affects wheat, barley and sorghum. If wheat is being attacked the ministry of agriculture and Crop Protection Unit will prioritize wheat over sorghum. Also in terms of scale—they prefer protecting 100,000 acres of wheat than 10 acres of sorghum.

The pest management government official interviewed refuted these accusations and said that they are working with all types of farmers, including large and small scale ones. In asking about how they prioritize efforts he answered: “The issue of food security guides our decision-making on where to control. Otherwise, decision is by first come first served.”

He also explained that the wildlife conservation rules limit their operations because the Queleas roost in national parks. In addition, he said that they are short of sufficient resources to address the problem. The annual budget of crop protection is KES 50 million (USD 507,000) and the budget for Quelea control is KES 20 million (USD 202,834). The budget was reduced in recent years and even though they need
more resources, no budget increase is expected. As a result, the possibility of using more sophisticated methods, such as early warning systems on Quelea attacks, is very limited:

We have an early warning system but we rarely used it due to financial constraints. Mostly, we react when farmers report to us. If we had more funding we could study migratory routes of the birds and have periodic colony surveys, which will improve our planning. Now it takes about a week to locate roosts. We basically follow the birds from farms after they attack them.

NGOs also felt inept in helping farmers control the Queleas, as indicated by an NGO senior executive:

We haven’t come up with a solution to the bird. Farmers ask us all the time “what can we do about the birds? We understand that you don’t have an answer to drought but how come you have not found a solution for the bird problem?” and we don’t have a good answer for them.

Other government officials also shared their frustration and said that often their hands are tied:

We lost a lot of seeds in the season that ended in October due to the Quelea. We lost 1,000 acre of seeds in one place which neighbors a national park. The fact that you neighbor a national park is a problem because you can’t use poison or explosives there.

Getting farmers to grow now is the hardest challenge. The contract is that we give them seeds and they give us bags of crops back. Now they don’t want to grow sorghum because of the bird.

However, the same government officials also said that they are trying to be creative and are thinking about new ways to support farmers’ struggle against the Quelea. One of them working in Western Kenya said:

Sometimes farmers change the season of growing sorghum to seasons when other crops are also growing to distribute risk. Also, the birds may not attack during these times because they would be somewhere else. However, sorghum does well in warm weather and when you grow it in cooler weather the yield is lower. Lose 20 percent between irrigation and rain fed but with lower risk coming from the birds. Is it worth it? We need to do the math on that.

We contract with farmer schemes and they line up the farmers. Quelea brings about losses and farmers lose and don’t want to grow crops again. We need insurance. There is insurance against natural disasters, against drought. Now we are starting a project on Quelea insurance and are looking for insurance partners.

The in-depth interviews with farmers and other stakeholders and the open-ended questions in the survey identified additional measures not captured by literature. These include for example the design of an innovative system where wire sheets are hung on flexible polls situated in different places on the farm and connected to each other. When an operator pulls on one end the system moves making loud sounds and reflects back sun light. This system however is relatively costly for smallholder farmers.
According to farmers, the system can cost up to KES 8,000 per acre (equivalent to $81) not including the payment, food and place to rest for hired labor to operate it. This calculation is based on a need per acre of: four wires at a cost of KES 1,500 each, ten polls at KES 800 total (a long poll that can be cut into three polls of the desired size costs KES 250), and iron sheets. Farmers who have plots with trees can save money on polls. In addition, most farmers hire a person to operate the system at KES 300 per day. Considering that Queleas stay around for six weeks at a time, labor costs amount to KES 12,600, USD128 per period. To put this number in context, the per capita income in Kenya is $1,300\textsuperscript{ccce}. Hence, assuming smallholder farmers do not earn more than the average income per capita, it is understandable why most of them do not spend over 10 percent of their annual income on such a system per period. In addition, according to farmers, even if such a system exists, it is often insufficient to deter the Queleas:

I have a system with flexible polls and a stretched wire in between with iron sheets. This system is generations old. Then a person can stand on one side of the field and pull the wire and the rest of the system moves and makes noise. It works but you still can’t sit for very long. You have to move around the field because if the birds only hear noise but don’t see something big moving they become suspicious and try to attack. If you have this system and your neighbor doesn’t, the birds attack his field. But if neighbors have the same system, the birds may leave and not come back. But then another flock may come. This system is expensive. I have two acres and it costs me a lot of money to protect them because I can’t do all the work alone, I hire someone. Then I pay this person KES a day and also give him food and a place to sleep. The government doesn’t give subsidies for setting up such a system and it’s expensive.

I have a similar system but use trees that are already on the farm. The birds get used to the system after a while so I still need to chase them with catapults and slingshots.

Another method discovered through the field study is planting sunflowers around sorghum and millet fields. The Queleas eat the sunflower seeds first and allow farmers to harvest in the meantime. This method however is also associated with additional costs and of limited effectiveness, as explained by one government officials supporting famers:

We plant sunflowers around the sorghum fields. The birds see the bright yellow color and they like the seeds and eat them first. In the meantime, the sorghum matures and hardens and they don’t like it any more. Queleas like the sorghum right before it is ready for harvest. This method has 40–60 percent success rate. Farmers don’t want to do it though because I it is wasting land space on sunflowers which are meant only as bird food rather than sorghum that can actually be eaten or sold. In our fields, we anyway need to have isolation space between crops anyway to avoid cross pollination so can do it. There is no loss opportunity for us but there is one for farmers.

Some farmers indeed choose to sacrifice such opportunity costs in designating a part of their farm as a bird-feeding ground, and focusing on protecting the rest. As one farmer in Homabay County explained:
I plant a buffer area. I dedicate a part of my plot for bird food. It is the same variety I grow on elsewhere but I let the birds eat that side and I focus on protecting the other side. They eat very systematically. They eat everything in an ordinary way and don’t jump around.

Theme 6: Farmers Need Help from Others to Protect Their Farms
Most farmers surveyed and interviewed said that it is virtually impossible to protect a farm from morning to evening for 12 hours per day, six weeks in a row, often twice per year. Still, 15 (14.2 percent) survey respondents do not have anyone help them. However, for the most part, farmers have helpers, either family members or hired labor. Most survey respondents (38, or 35.8 percent) use the help of their spouse and children. Sixteen (15.1 percent) hire one employee and 11 hire more than one (10.3 percent) (Table 4.16).

Table 4.16 Help in Quelea Control

<table>
<thead>
<tr>
<th>Who Helps You in Control of Quelea?</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>I do it on my own</td>
<td>15</td>
</tr>
<tr>
<td>My spouse</td>
<td>16</td>
</tr>
<tr>
<td>My spouse and children</td>
<td>38</td>
</tr>
<tr>
<td>My children</td>
<td>29</td>
</tr>
<tr>
<td>I hire 1 employee</td>
<td>16</td>
</tr>
<tr>
<td>I hire 2–3 employees</td>
<td>8</td>
</tr>
<tr>
<td>I hire more than 3 employees</td>
<td>3</td>
</tr>
<tr>
<td>Grandchildren</td>
<td>2</td>
</tr>
</tbody>
</table>

* Farmers were given multiple options to select from thus percentages do not add up to 100.

Whereas in the past Kenyan farmers could rely more on children, mandatory education law now requires that all children attend elementary school. One government official interviewed had bad memories from having to help his family protect crops as a child:

When I was a child we used to grow sorghum and millet and the birds would come. They had us as children stand up on high rise platforms and call when see the cloud of birds by shouting “they are coming!” Then all the kids would make noise to scare them. I hated this season mostly. Now that there is mandatory and free public education for children so grown-ups need to do this job.

In addition, children’s help is often unreliable, as explained by this farmer:

I have four acres of sorghum. Last time the birds were here they ate one of my acres despite attempts to quell it. It is very tiresome to play hide and seek with
the birds, make noise and chase them away. My wife and kids helped me a little but they usually wonder off to play instead.

Only 54 of the 107 farmers surveyed reported to have spent money on Quelea control. Among those spending any money, farmers spent an average of KES 5,050 (USD 51) per season with a standard deviation of KES 3,858.85. The minimal amount spent was KES 50 (USD 0.5) per season and the maximal amount was KES 15,000 (USD 152). However, even farmers who hired help said it does not always help protect their crops. Further, there are challenges ensuring that their workers do their job:

I planted 30 acres last year and expected 300 bags of sorghum but only got 15. And I still paid people to scare the birds but they just got overwhelmed and didn’t help.

When I am on the farm all day scaring birds I am pretty effective in protecting the plot. My wife and I take shifts—6am to noon and from noon to 6pm. If we are not there the whole time, the birds will eat everything. I have to hire someone to work in the rice field when I am busy scaring birds of the other fields. It is usually four people per acre to work in the rice field for KES 300 (USD 3) per person per day [amounting to USD 504 per season]. To make sure people show up to work I pay them every day for that the day and not for the full month. I prefer people that live close by because then I don’t need to provide them with a place to stay. I also prefer women because they are more reliable than men. Maybe because women are in charge of the food in the house so understand the importance of this work to food security. Young men drink and slack at work.

Another common coping mechanism reported by farmers and other stakeholders interviewed is diversifying from growing sorghum and millet, mostly to maize. As indicated in Table 4.17, of 106 farmers that responded a survey question on whether they had changed their farming behavior due to the Quelea problem, 80 (75.5 percent) said that they did. The most frequent change was a shift to growing maize (35 farmers, 43 percent), followed by shifts to cowpeas (19 farmers, 23.75 percent), green grams (17, 21.25 percent), and to beans (15, 18.75 percent). Thirteen farmers (16.25 percent) reported to have reduced the sorghum production without shifting to other crops (implying reduced earnings from farming overall).
Table 4.17 Change in Farming Behavior Due to Quelea

<table>
<thead>
<tr>
<th>Change of Farming System Due to Quelea</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shifted to maize</td>
<td>35</td>
</tr>
<tr>
<td>Shifted to cowpeas</td>
<td>19</td>
</tr>
<tr>
<td>Shifted to green grams</td>
<td>17</td>
</tr>
<tr>
<td>Shifted to beans</td>
<td>15</td>
</tr>
<tr>
<td>Reduced sorghum acreage</td>
<td>13</td>
</tr>
<tr>
<td>Shifted from white to red sorghum</td>
<td>11</td>
</tr>
<tr>
<td>Shifted to pigeon peas</td>
<td>7</td>
</tr>
</tbody>
</table>

As mentioned above, maize is not only less nutritious but also less resistant to drought than the traditional grains sorghum and millet. A government official explained:

Many [farmers] have shifted from sorghum and millet into maize. It is harder for the Quelea to eat maize as their bills are too small to attack the seeds in a maize cob, also known as corn. However, maize needs a lot more water than millet or sorghum and so is often not an option in semi-arid zones.

Some farmers shared negative experiences on the shift from sorghum toward the more safeguarded maize, for example a head of a farmer scheme in Tharaka Nithi County said:

This year [referring to 2014], the rain stopped early—in October. We had 100 percent losses in maize because it is very dry and maize needs water. The only thing that can grow in this climate now is sorghum and millet. But the only problem is the bird.

Farmers’ Perspectives on the Use of Lethal Preventative Bird Control Measures

Theme 7: Farmers Are Willing to Eat Queleas (However It May Not Ameliorate the Problem)

The survey asked farmers whether they would be open to eating Quelea birds. On hundred and five farmers responded to the question on if they had tried eating Queleas, out of whom 64.8 percent said they did said they had tried to eat the birds. To the question on whether they would be willing to eat Queleas, of 106 farmers who responded, 67 percent said yes, 27.4 percent said No and the rest (5.6) percent were unsure. Examining this willingness by age group, respondents in both ends of the age spectrum, 21–30 and over 60, were least open to this option (Table 4.18). The comparison of willingness by gender showed no meaningful differences between female and male farmers and did not produce statistically significant results.
Table 4.18 Willingness to Eat Queleas by Age Group

<table>
<thead>
<tr>
<th>Willing to Eat Quelea Bird</th>
<th>Percentage of Respondents in Age Range</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21–30 (N = 6)</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>40.0</td>
<td>67.0</td>
</tr>
<tr>
<td>No</td>
<td>60.0</td>
<td>27.4</td>
</tr>
<tr>
<td>Maybe</td>
<td>7.7</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>31–40 (N = 26)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>80.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>41–50 (N = 33)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>66.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20–40 (N = 22)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>72.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>51–60 (N = 22)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over 60 (N = 20)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>67.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>27.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total (N = 107)</td>
<td></td>
</tr>
</tbody>
</table>

The most frequently cited responses for unwillingness to eat Queleas were as follows:

- Fear that the birds might be contaminated by chemicals from elsewhere (34 percent). One farmer explained:
  
  Eating the birds? If you kill them using poison then the answer is no. If not with poison, maybe. But you can trap only 20–40 at a time which would not really affect their population.

- Eating the birds is against traditional values and beliefs, except for in the case of children (28 percent). A farmer explained that:
  
  These birds might be taboo because they are migratory so no one knows exactly where they come from and some think they are evil.

- Do not like the taste of the Quelea (24 percent), for instance:
  
  Youth won’t touch them either. Maybe if you turn them into sausages?

- One farmer was vegetarian. Other reasons cited by two farmers each were that it trapping Queleas would be too hard, and that eating wild birds is illegal. Government officials confirmed this point:
  
  You might not be able to sell birds as food because our food and drug administration need to check their source and because they are migratory it is hard to trace them. You raise an n interesting idea to examine Queleas for animal feed. That does not need to be inspected in the same way and the birds can get grinded as a whole with their feathers.

  People in Western Kenya eat them but it is on a very small scale. People may do it privately but not commercially. The KWS does not allow eating on a massive scale. Need to examine the law and guidelines on using Queleas as food and if killing them is allowed.

Officials also explained that even if eating the birds was common, this method would not eliminate the problem: “The birds can be used as a food resource but I am not sure that you can develop a market for thousands or millions of birds, but rather on much smaller scale. It might be different in other countries.”
Theme 8: Farmers Generally Oppose Mass-Killing of Queleas Using Chemicals/Dynamite

For the most part, farmers are not open to mass-killing of Quelea flocks by chemical spraying and/or explosives. When requested to state whether they agree with the statements “I am in favor of using chemicals/explosives for Quelea control,” 75/67 said that they either disagree or strongly disagree, respectively (Table 4.19). About a quarter of respondents (23 and 27 percent respectively agreed or strongly agreed with this statement).

Table 4.19 Openness to Killing Queleas Using Chemicals/Explosives

<table>
<thead>
<tr>
<th>Statement</th>
<th>N</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Unsure</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am in favor of using chemicals for Quelea control</td>
<td>105</td>
<td>35 (33.3%)</td>
<td>36 (34.3%)</td>
<td>10 (9.5%)</td>
<td>22 (21%)</td>
<td>2 (2%)</td>
</tr>
<tr>
<td>I am in favor of using explosives for Quelea control</td>
<td>104</td>
<td>31 (29.8%)</td>
<td>36 (34.6%)</td>
<td>10 (9.6%)</td>
<td>25 (24%)</td>
<td>2 (1.9%)</td>
</tr>
</tbody>
</table>

Farmers opposed such methods primarily on three grounds:

**Risk to Animals and Humans**

In response to open-ended survey questions, 39 of 78 farmers that answered said that they were afraid of having people and animals get hurt by such methods. For example: “Dead sprayed birds might be picked up and eaten by children, and can poison them.” “Domestic animals like dogs might find the dead bird and feed on them and consequently get poisoned also.”

While the pest management official said that their methods are primarily aerial and ground spraying of roosts with chemicals, other government staff said that they were against such measures, for example:

Poison is not an option. We have had instances when kids ate the birds, dogs, cats and lots of other wildlife. In pastoral environments there is a lot of wildlife even when not counting in the national parks, and we cannot risk that.

**Broader Adverse Environmental Impact**

Twenty other respondents expressed concerns regarding a broader adverse environmental impact: “I don’t support chemicals because they can poison water sources and we here depend on the river and chemicals can poison the river. I am also scared about the effect on bees because some of us are beekeepers.” “This method will affect balance of nature. Those animals and organisms depended on the birds for survival or some ecological function would be affected and might also die.”

A Kenyan Government official said these feeling may represent a larger political problem as: “In Kenya, environmentalists are against chemicals and there are quite many lobby groups.”
Unethical and Against the Community’s Values

Massive killing of Queleas was perceived to be “unethical” and against the community’s values: “It is God’s work to balance nature but not man’s doing by killing the birds.” “It is against the Christian faith to kill animals and birds if you don’t intend to eat them.”

Referring specifically to the use of explosives, one farmer said it is problematic in Kenya due to public fears of terrorism: “Dynamite? Not in Kenya. People will associate explosions with al-Shabaab11.”

Among the farmers who support mass killing of Queleas using either chemicals or spraying (around 25 percent of sample), most explained that considering the damage these birds inflict on farmers it is acceptable to kill them: “It will be fine to even burn them because they cause huge losses to farmers.” “Any method that can kill the birds is acceptable.” “It would be good and acceptable since the birds destroy a lot of crops in the event they attack.”

Others invoked reasons of cost-effectiveness. For instance: “Spraying will help to reduce the cost of controlling the birds.”

Several farmers support lethal methods but with a caveat that the chemicals are not harmful to the environment or that people are warned beforehand: “If the chemical being used will be environmentally friendly, then the method is acceptable.” “As long as the chemical don’t affect livestock and people, then the method will be good to control the menace birds.” “If the chemicals are used, people would need to be warned not to eat the dead birds.”

Farmers’ Perceptions Regarding the Use of UAS for Quelea Control

Farmers were asked to indicate to what extent they agree or disagree with multiple statements pertaining to their interest in adopting new technologies for Quelea control, including UAS (Table 4.20).

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11 Jihadi terrorist organization based in Somalia that fights Kenya.
Table 4.20 Farmers’ Perceptions on the Use of Innovative Quelea Control Methods, Including UAS

<table>
<thead>
<tr>
<th>Statement</th>
<th>N</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Not Sure</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am interested in innovative techniques and tools to manage the Quelea birds</td>
<td>107</td>
<td>0.94%</td>
<td>0.94%</td>
<td>1.9%</td>
<td>55.1%</td>
<td>41.1%</td>
</tr>
<tr>
<td>My community is interested in innovative techniques and tools to manage Quelea birds</td>
<td>106</td>
<td>0.94%</td>
<td>0.09%</td>
<td>7.5%</td>
<td>61.3%</td>
<td>29.3%</td>
</tr>
<tr>
<td>I am in favor of using mechanized methods for pest management and Quelea control</td>
<td>105</td>
<td>2.9%</td>
<td>8.6%</td>
<td>3.8%</td>
<td>56.2%</td>
<td>28.6%</td>
</tr>
<tr>
<td>I prefer highly visible methods of pest management</td>
<td>105</td>
<td>0%</td>
<td>5.7%</td>
<td>3.8%</td>
<td>57.1%</td>
<td>33.3%</td>
</tr>
<tr>
<td>The decision to adopt any control method depends primarily on its price</td>
<td>106</td>
<td>2.8%</td>
<td>14.2%</td>
<td>2.8%</td>
<td>61.3%</td>
<td>18.9%</td>
</tr>
<tr>
<td>The decision to adopt any control method depends primarily on the difficulty of operating it</td>
<td>107</td>
<td>0%</td>
<td>20.6%</td>
<td>8.4%</td>
<td>50.5%</td>
<td>20.6%</td>
</tr>
<tr>
<td>The decision to adopt any control method depends on my farmer scheme and farmers around</td>
<td>107</td>
<td>2.8%</td>
<td>27.1%</td>
<td>10.3%</td>
<td>44.9%</td>
<td>15%</td>
</tr>
<tr>
<td>I am in favor of using a UAS (UAV, drone) to scare off the Queleas</td>
<td>103</td>
<td>1.9%</td>
<td>2.9%</td>
<td>5.8%</td>
<td>62.1%</td>
<td>27.2%</td>
</tr>
<tr>
<td>My neighbors will be in favor of using a UAS to scare off the Queleas</td>
<td>107</td>
<td>0%</td>
<td>1.7%</td>
<td>7.5%</td>
<td>67.3%</td>
<td>23.4%</td>
</tr>
<tr>
<td>I am interested in learning more about the potential use of UAS to scare off the Queleas</td>
<td>106</td>
<td>0%</td>
<td>0%</td>
<td>1.9%</td>
<td>48.1%</td>
<td>50%</td>
</tr>
<tr>
<td>I am more likely to adopt a UAS for Quelea control if other farmers in my community have already adopted it</td>
<td>107</td>
<td>6.5%</td>
<td>3.8%</td>
<td>4.6%</td>
<td>59.8%</td>
<td>25.2%</td>
</tr>
<tr>
<td>Using UAS for Quelea-control may have negative security implications</td>
<td>105</td>
<td>14.3%</td>
<td>34.3%</td>
<td>16.2%</td>
<td>24.8%</td>
<td>10.5%</td>
</tr>
<tr>
<td>Using UAS for agriculture may have negative implications in terms of privacy</td>
<td>106</td>
<td>16%</td>
<td>37.7%</td>
<td>14.2%</td>
<td>26.4%</td>
<td>5.7%</td>
</tr>
<tr>
<td>Using UAS for Quelea-control or other agricultural applications may attract young people to work in agriculture</td>
<td>107</td>
<td>1.9%</td>
<td>3.7%</td>
<td>3.7%</td>
<td>34.6%</td>
<td>56.1%</td>
</tr>
</tbody>
</table>

Theme 9: Farmers and Stakeholders Are Interested in Innovative Quelea Control Methods, Including UAS; Farmers Strongly Prefer Mechanized and Visible Methods

As shown in Table 4.20 and the graphs in Figure 4.9, 103 of the 107 farmers surveyed (96.2 percent) are interested in innovating Quelea control methods. Similarly, 96 farmers (91 percent of the 106 farmers that answered this question) said that their community is interested in innovative techniques and tools to manage this problem. The vast majority of farmers are interested in mechanized (89, 85 percent of the 105 farmers that responded to this question) and in highly visible methods (95 or 90.4 percent).
Figure 4.9 Interest in Innovative and Mechanical Control Methods, by Statement

I am interested in innovative techniques and tools to manage Quelea birds

My community is interested in innovative techniques and tools to manage Quelea birds
I prefer highly visible methods of pest management

I am in favor of using mechanized methods for pest management and Quelea control
The decision to adopt any control method depends primarily on its price.
I am in favor of using a UAS to scare off the Queleas.

The decision to adopt any control method depends on my farmer scheme and farmers around.
I am interested in learning more about the potential use of UAS to scare off the Queleas.

My neighbors will be in favor of using a UAS to scare off the Queleas.
I am more likely to adopt a UAS for Quelea control if farmers in my community have already adopted it.

Using UAS for Quelea control may have negative security implications.
Using UAS for agriculture may have negative implications in terms of privacy.

Using UAS for Quelea control or other agricultural applications may attract young people to work in agriculture.
A similar sentiment was expressed in interviews with NGO and government personnel. A senior NGO member said: “They roost very far from where they attack so it is hard to locate them. We scare birds from fields with guns but that is not enough. There is currently no technology to deal with the problem.”

All farmers surveyed but three (104, or 98.1 percent) said that they would like to learn more about UAS to scare off Queleas. Because most respondents had already expressed their negative views on lethal preventative methods, this section did not examine their perceptions vis-à-vis using UAS to chemically spray roosts and breeding colonies. Ninety two farmers (89.3 percent of the 103 that answered this question) said that they favorably see the use of UAS for scaring Queleas, and 97 farmers (or 90.7 percent of the full sample) said that their neighbors would be in favor of this technology.

As farmers explained for instance: “We are all desperate about the birds. We are all willing to try [UAS]. We like the idea because it’s not cumbersome and relieves us of the hard work.”

Drivers and Barriers to UAS Adoption for Quelea Control

Theme 10: Farmers Perceive Cost and Technical Difficulty as Potential Obstacles

Cost as a Possible Challenge

Most farmers surveyed (87 out of 106 who responded to this question or 80.2 percent) agreed with the statement that the decision on whether to adopt any bird control method, including UAS, depends on its price. In response to an open-ended survey question asking farmers to state what they see as the most important challenge to UAS adoption, 21 percent of the 84 respondents (18 farmers) cited the issue of cost. Of these responses, 83 percent were given by female farmers whereas only 17 percent by males. The age group that seems most concerned about cost is 41–50, representing 44 percent of respondents (Figure 4.10).

![Figure 4.10 Cost as a Main Challenge to UAS Adoption, by Gender, Age](image)

The issue of cost was raised also in in-depth interviews with farmers:
Drones are welcome. They do not conflict with wildlife and so the question comes down to costs and how many you need. Maybe we can just hire the drone for one month in December–January and then another one in May–June?

Most Government representatives and NGOs interviewed agreed that this technology is likely to be too costly at household level however suggested different models of implementation (discussed later in this chapter). They also explained however that the calculation should take into consideration the cost of maintaining the status quo:

UAVs will be too expensive for smallholder farmers unless through some cooperation. On the other hand, what is the cost of doing nothing? If farmers work so hard [in growing crops] and end up losing everything [due to Queleas]—what is the cost of that? Need to look at the cost of drones versus the cost of losses. There is another cost to food security—if people stop growing these healthy crops because of the birds.

**Technical Operation as a Possible Challenge**

Most farmers (76, or 71.1 percent) agreed with the statement that the decision to adopt any method depends primarily on the difficulty of operating it. Over half of farmers responding to the survey’s open-ended question on the main challenge to UAS adoption (54 percent; 45 farmers) pointed out that operating the equipment would likely be a challenge. Again, more female farmers are worried about this aspect than male, and the age group most concerned is the 41–50 year old (Figure 4.11).

![Figure 4.11 Operational Difficulty as a Challenge to UAS Adoption, by Gender, Age](image)

Other technical issues raised in answers to this open-ended question were the (lack of) means of powering/charging UAS (24 percent of responses; 20 farmers) as well as repair and maintenance (19 percent; 16 farmers). In interviews with farmers, these issues were not raised independently by farmers. When raised by the study team, farmers gave mixed responses, depending on the county where interviews were held. In Makuemi for example farmers said that many of their peers are illiterate and would not know how to operate a computer. One young female farmer (in the age group 21–30) said that she learnt how to use a computer in secondary school (equivalent to junior high) but that she
does not practice it because she does not have a computer at home. In Homa Bay, a group of farmers said that they are technically savvy and can operate computers. Similarly, while in the Sub-County Kibwezi East there is no power at homes (but the center village is connected to a power), this was not a problem in Homa Bay.

Theme 11: Farmers Are Only Partially Concerned About Security and Privacy Implications

Farmers surveyed and interviewed had mixed views on both security and privacy issues associated with UAS. In general, when farmers were asked open-ended questions regarding possible challenges to UAS adoption, they did not cite these security and privacy as major factors. However, when prompted to consider these issues, either in the survey or in the interviews, they tended to acknowledge that they may pose obstacles to successful adoption of this technology. The differences between farmers’ responses to open-ended versus close-ended questions implies that security and privacy are not as strongly associated with UAS technology as cost or technical issues. On the other hand, government officials interviewed had expressed concerns regarding both security and privacy.

Security

While 51 of the 105 farmers responding to this question (48.6 percent) agreed with the statement that “Using UAS for Quelea-control may have negative security implications,” only three farmers (3.5 percent) cited this reason as a challenge to UAS adoption when answering to open-ended questions. Similarly, security was not brought up independently by farmers interviewed. When asked about this potential problem, most farmers did not consider it as a significant barrier. As one head of farmer scheme in Makuemi explained: “It [UAS] will be welcome but not if mounted with a payload that makes explosion sounds. That will scare people. But a flying machine that scares birds will mesmerize people.”

Another head of scheme in the Tharaka North sub-county said:

If [UAS are] used purely for agriculture farmers would not care about their military uses. This is a very peaceful region and we are not worried. As long as the government allows the use and there is no bad history of drones, farmers would welcome the use of drones to better the land and improve crops yield.

Two Government staff echoed this sentiment. They explained:

I don’t think people know what drones are. Might be variation inside Kenya for example in areas close to Somalia. As long as this technology is introduced in a structured way it should be okay.

And

On the face of it, I don’t think there will be fears. Maybe later after it is introduced, people may start asking questions. At first though, the excitement of responding to the birds will override any potential issue that may arise about this technology. If it proves to be effective, and there will be an effort to sensitize people to this issue before hand, it should be okay.
However, another Government official disagreed. According to him,

The first public exposure to UAVs was not long ago. We had a national celebration and one media agency mounted a camera on a drone and it was hovering over the stadium where the celebration was held. No one knew what it was and then the police realized it is operated by someone outside the stadium, they asked this person to shut it down. . . . People see drones as a security-related issue. People are scared of drones. There has been no security incident but it’s still perceived as risky. People are afraid that an IED could be mounted on a drone.

A fourth Government official agreed that UAS technology can pose a security threat but proposed passing and enforcing legislation that would stipulate their appropriate uses. He said:

Farmers don’t know what drones are but we—those that know—need to protect those that don’t know. Need to regulate against bad people who will use this technology for example to track people carrying money and robbing them. It is like gun control. People using drones need to be vetted. In Tanzania there is a gun store on every street corner. In Kenya, none. The same logic should be applied to this technology.

Privacy

The contrast between the survey’s close-ended and open ended results and those of the in-depth interviews are even more pronounced in the case of privacy. Whereas 57 of the 106 farmers responding to this question (53.7 percent) agreed with the statement that “Using UAS for agriculture may have negative implications in terms of privacy,” none of the farmers surveyed who responded to the open-ended questions cited privacy as a challenge to UAS adoption. Privacy was also not raised independently by farmers in interviews, and even when they were encouraged to speak about this issue, they said that it does not pose a problem. For instance: “We don’t care about privacy in Kenya. We will welcome other uses [of UAS] as well. Just need to be sensitive, inform people about it and they’ll be okay with it.”

The government official concerned about security explained however that Kenya’s politicians are starting be worried about privacy and that it may affect adoption of UAS: “Privacy is starting to be a problem in Kenya because the media does not respect politicians’ privacy, and so they are starting to be concerned about that.”

Theme 12: New Technology, Including UAS, Can Draw More Youth into Agriculture

A recurring theme expressed in the survey and the interviews with all stakeholders was the aging of the Kenyan farmer population and the lack of interest on the part of youth to pursue agriculture. A young female farmer (between the ages 21–30) said that agriculture is insufficient for her livelihood. Thus, she has to do business on the side including make and sell detergent in the market and so forth. She said: “If I had other options, I would never choose agriculture.”
According to farmers, technology in general, including UAS, can help reverse this trend and draw more young people into farming. A head of a farmer scheme said for example:

Sixty percent of farmers are over 50 year old. Agriculture is not very attractive in Kenya. The inputs are very expensive. We are worried about the future of agriculture. Most farmers are illiterate and cannot use technology. But to improve agriculture you need technology. Agriculture needs to become attractive for young people who want to earn money and not work physically so hard. The use of a new technology like UAS can actually draw in young people who will get excited about the opportunity to drive a tractor for example or use technology. Irrigation doesn’t exist. Instead it’s all manual hard work in the sun.

Another farmer added that the Government is not doing enough to address this problem:

The government is also worried about the future of agriculture but are they doing anything? No. Are they encouraging older farmers to give titles to their children? No. Are they adding technologies to the agricultural value chain? No. Are they facilitating the entrance of young people into the agricultural value chain? No. If we mechanize agriculture young people will join.

The survey results strengthen these findings—91 farmers, 97 percent of entire sample, agreed with the statement that “using UAS for Quelea-control or other agricultural applications may attract young people to work in agriculture.”

**Legal Considerations**

Only four farmers of the 84 who responded to the open-ended survey question about the main obstacles to UAS adoption cited legal reasons and said that they were not sure if such a technology is allowed by the Government. However, findings pertaining to this issue are presented here because it came up several times in in-depth interviews with Government officials.

Government officials explained that there is currently a legal vacuum around the issue of UAS technology. Following the incident in which a UAS was operated by a media outlet reporting on a national celebration in Nairobi, the Government has been debating the legal status of such systems but no decision has been made thus far. For now, there is legal ban on the use of UAS for commercial and civilian purposes, as explained by a Government representative working in the Ministry of Transport & Infrastructure, which is in charge of aviation as well:

Since then [referring to the UAS incident], there have been a few meetings on how to deal with UAVs but no outcome yet. We are likely to follow the U.S. model in terms of legislation. Now there is a ban over drones put forward by the Director General of Kenya’s Civil Aviation Authority [see Figure 4.9]. No further flying drones until there is a regulation in place. But this is not really authoritative because if they catch someone flying a drone, on what grounds can they bring him to court? There is no law yet. There are people around with hobby drones and there are also private conservatory groups using them to
monitor natural resources and animal movements. As far as I know, they all are continuing to use them despite this ban.

4.8 Discussion & Conclusion

In this chapter, I reviewed scientific and commercial literature, held in-depth interviews with Quelea and UAS SMEs, and conducted a field study in Kenya which included a survey of smallholder farmers and interviews with farmers, NGO staff and Government officials. The objective of this chapter was to assess the compatibility of UAS technology for Quelea control in Sub-Saharan Africa taking into consideration technical and non-technical considerations. One of the strengths of this work is its comprehensive approach to assessing this prospect. Specifically, the rich depiction of key informants’ perceptions on the Quelea problem as well as UAS has helped illuminate the drivers and barriers to adoption of UAS technology in this context.

Notwithstanding the novelty and richness of this analysis, this chapter has some methodological limitations which may have affected the results. First, the survey was conducted among a convenience sample and thus is not representative of the full population of interest – smallholder farmers in Sub-Saharan Africa, or even all Kenyan farmers. Thus for example, while these Kenyan smallholder farmers do not tend to support lethal bird control methods, farmers in other counties as well as in other countries may have different views on the use of chemical spraying, explosives and even eating Queleas.

Nevertheless, while convenience samples may not be representative, the survey sample included female and male farmers, from various age groups, who grow different types of small crop grains (with an emphasis on the traditional grains - sorghum and millet), and who have been affected by the Quelea bird. Because the Quelea is nourished in various small grain crops, some of the findings (including the magnitude of the problem, effectiveness of traditional bird control measures and so forth) may perhaps be generalizable to other smallholder farmer populations.

In addition, the samples of informants for the in-depth interviews—with SMEs, farmers, NGO staff and Government officials—were developed purposively and again may not be the representative of these four populations. Moreover they do not represent all stakeholders along the small crop grain value chain, including for example commercial farmers, processors and other private sector actors. At the same time, this study takes a first stab at holistically analyzing the suitability of UAS for Quelea control. Accordingly, it sought to represents different geographical regions (albeit in Kenya only), various roles along the sorghum and millet crop production value chain, and key informants on the Quelea problem as well as the proposed UAS-based solution. Thus, even though the data gathered may not be representative of all stakeholders, this chapter’s results are suggestive and provide valuable input for assessing if, and under what circumstances, UAS may provide a solution for Quelea control.

The analysis in this chapter produced multiple results. In short, the literature review and interviews with SMEs have established an initial technical match between the requirements posed by the Quelea problem and the specs of UAS, envisioning a Quelea-specific UAS that can integrate visual and auditory measures to scare away bird flocks from farmlands. At the same time, they also flagged some important
technical and non-technical challenges associated with the potential use of UAS in such missions. Future research on this prospect should be based on experiments which would clarify whether UAS can actually perform the task. Specifically, this analysis should consider which characteristics of a UAS would make it compatible paying special attention to size, endurance, degree of autonomy, and communications range.

The survey and in-depth interviews with farmers, NGO representatives and government officials further investigated these barriers. Yet, they have also highlighted important drivers that may promote the adoption of UAS technology, as explained above in detail. Table 4.21 summarizes all key drivers and barriers identified in this chapter.

**Table 4.21 Key Enablers and Obstacles to Adoption of UAS Technology, as Perceived by Key Informants Surveyed and Interviewed**

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude of Quelea problem</td>
<td>Cost (affordability)</td>
</tr>
<tr>
<td>Absence of existing effective Quelea control measures</td>
<td>Technical issues (operational difficulty, power, repair &amp; maintenance (technical feasibility))</td>
</tr>
<tr>
<td>Protection of crops from Queleas requires assistance</td>
<td>Mission fit (size/number of UAS to scare off Quelea flock)</td>
</tr>
<tr>
<td>Opposition to lethal methods</td>
<td>Security issues</td>
</tr>
<tr>
<td>Interest in innovative, mechanical, highly-visible bird-control measures</td>
<td>Privacy concerns</td>
</tr>
<tr>
<td>UAS may draw youth into agriculture</td>
<td>Legal restrictions (and political issues)</td>
</tr>
</tbody>
</table>

The most important drivers identified are borne from a combination of factors. Farmers are devastated by the Quelea impact and do not have any effective means at their disposal to mitigate it. While in other countries (for example South Africa) lethal methods are acceptable, the key informants interviewed and surveyed here oppose such measures. Stakeholders are interested in new bird control means that would be effective, highly visible, and mechanized to reduce their burden having to chase and yell at birds twice per year for six weeks at a time, for 12 hours per day, often without full success. In that regard, any technology—be it UAS or something else—can potentially satisfy stakeholders in the small grain value chain. An interesting finding pertaining to UAS specifically is the potential power of this innovative technology to draw more young people into agriculture. The aging of the farmer population in Kenya is worrisome and any step that can reverse this trend is considered welcome.

While the drivers would clearly help motivate stakeholders to consider the adoption of UAS for Quelea-control, it is useful to discuss how some of the key obstacles may be addressed in a future implementation process. The following discussion includes ideas proposed by NGO and Government representatives as part of this chapter. While other challenges may be associated with UAS technology (communication for instance, as mentioned in Chapters 2 and 3), this section, which is organized by barrier type, is limited to those identified through this chapter’s data collection channels—affordability,
technical issues, the compatibility of UAS for this mission, security and privacy concerns (or the stigma associated with military “drones”), and legal restrictions.

**Affordability**

Personnel from all NGOs interviewed said that in principle their organizations can help sponsor UAS for Quelea control. Prior to doing so however, they said that it would be useful to have a detailed cost–benefit analysis that would take into consideration the full agricultural losses attributable to the Quelea problem and accurate projections of the cost savings that this technology can bring about. Such an analysis would allow for a more sensible assessment of the costs of purchasing and operating UAS. As mentioned above, such an assessment should take into consideration not only opportunity costs but also implications to food security. One NGO staffs said that his organization has an innovation fund that may be willing to support such a program.

Government representatives said that they may offer to subsidize such a service. As one government official explained: “Farmers can pay for this as service but we will provide subsidies. We can do it. We work with farmers in blocks of 200–1,000 acres so can provide such services to blocks.”

Further, Government staff said that if UAS can conduct other agricultural missions that would make this technology more cost-effective and appealing to them:

> Once the drone technology is used we can also use it for other missions for example, to optimize information using sensors. We are working on digitizing our work and this can be part of our efforts. This can be helpful actually in portraying the drone technology a platform for multiple uses. It will make their introduction easier.

Another NGO representative said that the adoption of this technology may be suitable for private–public partnerships between breweries that use sorghum and the Kenyan Government: “Sorghum is now promoted for use in beer production in Kenya, Uganda and Tanzania. These commercial companies may be another player interested in protecting sorghum crops and improving yields and thus helping to fund such a program.”

Finally, a Government staff working in Kakamega County mentioned that adopting UAS for this mission may have undesired economic implications related to labor issues:

> If the technology is substituting people who are getting paid to scare birds it may raise labor issues. To protect 60 acres of sorghum we pay KES 150,000 for the whole period. We employ people who live there, mainly women because the men are busy fishing in the lake.

Thus, any implementation plan should consider the effect on these people and how to promote alternative ways for them to earn money.
Technical Feasibility and Mission Fit

SMEs expressed concerns that given the size of Quelea flocks, one UAS may not be sufficient. Similarly, they said that the size of the UAS may need to be bigger than that of the BirdX prototype for example. Farmers, NGO and government personnel were more worried about the technical difficulty of operating the equipment, and the required means of powering, repairing and maintaining it. One suggestion that addressed both sets of issues was brought up other NGO personnel supporting farms of various sizes. Specifically, they proposed to fund a pilot program in one or two of these farms. Such a pilot would help test the effectiveness of this technology, the technical requirements of operating and maintaining it, as well as its costs in practice.

A government official proposed to view bird control as a public service, hereby addressing both cost and technical feasibility questions:

If this is a national-level initiative, we and other organizations can come in to provide this service with the objective of alleviating hunger and food insecurity. It can be thought of as a public good. We can help training operators and/or provide these services. We can also find many other uses for drones. For example, cattle theft is a big problem throughout Africa so we can use this technology to monitor cattle. The Tsetse mission you described can also be very useful the way we see it. In short, we can help with funding and operation.

Security and Privacy Concerns (and the Stigma Associated with “Drones”)

Three populations interviewed in this chapter—smallholder farmers, NGO staff, and Government officials—touched on the perceptions associated with UAS or “drone” technology and the importance of addressing them in the implementation process. Virtually all farmers surveyed and interviewed did not know what UAS are. Following an explanation of the technology, they said they would still welcome it. Some farmers said that the introduction of UAS to the farmer community should be done properly through consultation with community leaders. As one farmer explained:

I like this idea. Better than throwing stones. I don’t know about the stigma. If the issue is brought properly with proper introduction, if you call the village chiefs and introduce it to them and explain—there should be no problem.

NGO and Government personnel were more worried about the public’s perceptions of UAS, especially in areas not surveyed closer to the border with Somalia. However they also said that these fears can be ameliorated if addressed in advance.

Legal and Political Issues

As noted above, the legal of status of UAS in Kenya is unclear, although the Government is likely to follow the U.S. FAA’s model. In addition, the Government is concerned about privacy and security concerns as discussed in detail above. A Government official from the Ministry of Transport & Infrastructure explained that if there is an interest in testing and using UAS for Quelea control, it needs to be managed politically, saying that:
In Kenya to be successful you need the tenacity to push through a new thing. If the agenda is pushed for example by smallholder farmers, it will not receive a hearing in parliament. But if, on the other hand, it is pushed by the United States, there will be a parliamentary hearing, we will design a plan and give authority to try this technology. It will be expensive in terms of time and labor devoted to lobbying for this, like for any other cause. If perfectly done, you will have to have a strong political player on your side. For example if you come with the Israeli ambassador or the U.S. ambassador to Kenya that would be an excellent starting point. You will also need to get blessing of our ministry.

The results imply that UAS can be tried as means for Quelea control but policymakers should take note of the multiple obstacles raised in the survey and interviews and address them in advance. Also, they should capitalize on the presence of several enablers that can ease the adoption of this technology and make stakeholders not only along the agricultural value chain, but also politicians, private sector actors and so forth, more amenable to pursuing this potential solution.
Chapter 5. Assessing the Feasibility of Adopting UAS for Agriculture in Africa: Analytical Framework

[The] number of variables—social, legal and institutional as well as economic and technological—which might retard the [technology] diffusion process is virtually limitless. [N. Rosenberg, Factors affecting diffusion of technology]

5.1. Introduction

Chapter 2 has surveyed the literature on agricultural UAS applications and Chapters 3–4 have established that UAS may offer a solution to two of Africa’s most pressing agricultural challenges. However, while the technical match between agricultural requirements and UAS specs is necessary, it is insufficient for this technology’s adoption. Literature suggests that technical aspects of technological innovations constitute only a small part of the potential obstacles to their adoption. Multiple factors, and the complex relationship between them, determine whether new technology applications will be adopted, and if yes, how. The combination of these factors encapsulates the complex policy, political, social, and economic landscape in which technology adoption occurs. Thus, even given a need and a theoretical match, the adoption and implementation of UAS may not be straightforward for many African countries, depending on the presence of other factors that can either promote or hinder these processes.

While Chapter 4 examined some of these factors, it only focused on one application of UAS—control of the pest Quelea bird—and only in several counties in Kenya. Thus, its findings are not indicative of the feasibility of employing this technology in other agricultural missions across the continent of Africa.

The objective of this chapter and subsequent five chapters (6–10) is twofold. First, it is to assess to what extent non-technological factors may in general promote or hinder the processes of adoption of UAS for agriculture. Further, it is to examine the presence or absence of such factors in 36 African countries and exploit inter-country variation to suggest where UAS adoption—for any purpose—is more or less likely and under what circumstances.

In the context of the study’s research plan, these chapters correspond to phases 4 and 5 of the work, which are highlighted in Figure 5.1:

\[ \text{References:} \]

\[12\] N. Rosenberg, Factors affecting diffusion of technology, Explorations in Economic History, 10 (1) (1972), pp. 3–33
To meet these objectives, this chapter opens with an overview of technological innovation diffusion process and an introduction of non-technical factors that may or may not influence the technology adoption process. It then reviews literature on different approaches to analyze technological innovation adoption. Finally, it introduces the framework that will be used to assess the likelihood of UAS adoption in African agriculture, and discusses its advantages and limitations.
Consisting of different elements, the framework itself is broken down into five chapters. Chapter 6 analyzes which capabilities are required to produce, import and operate UAS by countries. Chapter 7 examines affordability questions and looks at whether countries can afford this technology. Chapter 8 assesses the role of governance and institutions have in technology adoption, and Chapter 9 studies how differences in cultural attributes may influence this process. Chapter 10 concludes this part of the study by combining the results of chapters 6–9 into an aggregated feasibility score and by illustrating how it varies between countries in the African continent.

5.2. Technological Innovation Diffusion

To determine and assess the extent to which non-technical factors may influence of UAS adoption for agriculture in Africa, it is useful to refer to the Diffusion of Innovations theory, which seeks to explain how, why, and at what rate new ideas and technology spread through cultures. According to this theory, three types of factors facilitate or hinder technology adoption and implementation including:

1. characteristics of the technology itself;
2. characteristics of adopters; and
3. the means by which adopters learn about and are persuaded to adopt the technology. The technology Acceptance Model (TAM) builds upon this theory and introduces specific TAM variables, which are perceived usefulness and ease of use, as well as extended variables including perceived credibility (the absence of risk), perceived self-efficacy, and perceived financial cost.

Among the technical factors that enhance the adoption of a technology are “trialability”—can it be tried out? “Observability”—are results observable? “Relative advantage”—is it better than present technology? “Complexity”—is it easy to use? And “Compatibility”—is it suitable for the circumstance? While there is no question about the “trialability” and “observability” of employing UAS for agricultural missions, reservations regarding the technology’s “relative advantage,” and “compatibility” motivated the analysis conducted in earlier chapters of this study to address the broad version of Research Question 1, i.e., Can UASs add value to agriculture in Africa?

Indeed, findings from chapters 2–4 suggest that UAS can meet the technical qualifications to mitigate a variety of agricultural problems, are advantageous relative to comparable technologies currently used for similar missions, and are compatible with the unique features of Africa’s landscape. Nevertheless, these components represent only of one piece of the story. As mentioned, literature indicates that non-technical factors are often more detrimental to the technology adoption process than the technical offerings of the technology itself.

Specifically, the context and environment in which a technology is to be employed may give rise to more significant barriers (or drivers) that can impede (or promote) its adoption even if technically suitable to the issue. These barriers and drivers may be institutional, cultural, economic, or related to the

13 Adoption and diffusion may appear to be used as synonyms in the study, as they are closely related. Diffusion occurs when a user adopts an external technology.
technical skill of the workforce. Subsequent chapters will elaborate on these types of drivers and barriers. However, a short explanation on their nature and brief examples provide context and set the stage for the subsequent analysis and discussion.

5.3. Drivers & Barriers

Drivers are the motivations or forces that will enable policymakers, as well as individual users, to choose a technology to meet a certain need and to acquire capacity to sustain the application of that technology. Barriers are the opposites of drivers: They are hindrances to the implementation of technology. Drivers and barriers frequently stem from the same sources. Their main difference lies in whether the source is available or absent. For example, whether funding is available to purchase or develop the technology (or not); whether the population is technologically-savvy; whether public opinion is favorable toward the technology; whether it is legal; and so forth.

Some barriers and drivers to technology adoption have to do with the technology itself, including issues of “trialability” and “observability.” For example, the performance of the technology may be uncertain, either because the technology is not yet proven or because it has complex interactions with other systems that are difficult to assess and anticipate. In that regard, agricultural applications of UAS are an emerging field and as a result there is still insufficient evidence to prove beyond doubt their added value. Additional technical drivers and barriers may motivate or prevent the performance of a technology, such as cloud cover, winds and others.

Other drivers and barriers may be institutional, economic, cultural, or of another type. For example, to be formally adopted the technology has to be legal. Different countries have different laws and regulations that administer their national airspaces. The Federal Aviation Authority (FAA) in the United States, for instance, has been ordered to change regulation to allow the safe integration of civil UAS into the national airspace system by September 2014, but has still not done so in a comprehensive manner. In February 2015, the FAA proposed safety rules for small UAS (under 55 pounds) conducting non-recreational operations. These rules limit flights of the small UAS class to daylight and visual-line-of-sight operations, as well as specify new height restrictions, operational limits, requirements for operator certification, aircraft registration, and others. The proposed rule also includes the prospect of making more flexible rules for “micro” UAS (under 4.4 pounds) in the foreseeable future.

As for all other UAS classes, the law for now still prohibits the flight of commercial UAS in U.S. airspace above the altitude of 400 ft. An exception can be made if UAS operators have obtained a Special Airworthiness Certificate in an experimental category, a frequent practice by research universities that develop UAS, payloads and new applications. In contrast, other countries, including Japan, Australia and Canada, have passed regulations that permit large scale agricultural UAS uses. While there is insufficient data on airspace laws and regulations in African countries, they are likely to adopt some version of the legal approaches already in place in other countries. In Kenya, for example, a government...
official within the Ministry of Transportation tasked with the national airspace said they are currently working to adopt the US approach to UAS.

In addition, for a technology to achieve social acceptance, the following conditions need to be fulfilled: “societal concern is not unduly large, there has been sufficient articulation of the pros and cons so that choices can be made consciously, and the new product is actually used.” Social acceptance of technology is especially interesting in the context of UAS as it is considered a “stigmatized” technology. Public perception of such controversial technologies is often unclear and inaccurate, which then leads to stigmatization. This is due to the combination of a host of factors: perceptions of unusually higher risk, distrust in management and government, and perception of failed promises. UAS is not the only stigmatized technology out there. Prominent examples of this phenomenon include GMOs and nuclear energy. Specifically, in the 1950s nuclear energy was seen as an inexpensive and safe source of power production. However, after the 1986 Chernobyl disaster in Ukraine, and the 2011 Fukushima Daiichi nuclear disaster in Japan, the public has grown increasingly skeptical about the safety of this form of energy.

The stigma associated with UAS is mostly a result of debates about “drones” and U.S. military strikes in Afghanistan and Pakistan, revolving around issues of efficiency (unmanned versus manned missions), ethics (desensitized killing), and accuracy (as it pertains to collateral damage and indiscriminate civilian deaths). In addition, UAS bring about privacy concerns among individuals and groups who fear this technology would be used to spy on them. The stigmatization of technology can pose significant challenge to its social acceptance. Chapter 10 will discuss the influence of cultural and social norms on technology adoption and assess the extent to which these factors may affect the likelihood of adopting UAS for agriculture in Africa.

Finally, prices naturally shape consumer preferences for one technology or another thus cost and financing schemes are clearly crucial for the technology adoption process. Cost may be calculated on a net basis (that includes acquisition, personnel and maintenance of a technology) or to include the potential cost savings resulting from employment of the technology. UAS for instance can be costly on a net basis, even if not costlier than manned aircraft, as demonstrated in the Tsetse eradication mission analysis. However, as platforms for onboard sensors that provide accurate and timely information and may lead to a more judicious use of water, fertilizer and pesticides, the cost–benefit of UAS should extend beyond their net effects.

Aside from the financial costs, careless use of farming inputs can incur high ecological costs including environmental contamination, soil degradation, water waste, and wildlife damage, which are not easily measured. Hence, while important, the calculation of potential cost savings is not trivial. Cost is also relative and depends on the local context. A technology that is too costly for one country may be considered more reasonable for another. Chapter 7 assesses to what extent African countries can assume the financial burden of paying for UAS technology.
The variety of aforementioned drivers and barriers that can influence the acceptance of UAS technology will be holistically accounted for in the framework introduced in Section 5.4. Depicting these elements, and the relationships among them, will augment the analysis of the first part of the study that examined how suitable UAS are to address some of Africa’s agricultural challenges. Combining these elements will help assess the likelihood of successful adoption of agricultural applications of UAS in the continent. Finally, where applicable, the analysis will better enable decision-makers adopt the technology in a manner that fully addresses significant ethical, safety, and public concerns. Where problematic, it will point at steps which decision-makers can take to overcome such barriers and adopt the technology.

5.4 Technology Adoption Approaches: Review

Literature on technology adoption in developing countries, and even specifically in Africa, exists and includes empirical quantitative and qualitative approaches as well as theoretical frameworks. Nevertheless, by the time of writing this study, the author was not able to find studies specific to UAS technology adoption for commercial purposes. Therefore this section introduces approaches pertaining to other technologies. These in turn were helpful for the development of an independent framework for assessment of the likelihood that African countries can successfully adopt. The approaches reviewed are divided into two types: micro—those examining individual/group behaviors; and macro—capturing elements that affect technology adoption at the country level. The latter category is particularly informative for this study however it is useful to briefly introduce micro level analyses as well, especially because these are more common.

Technology Adoption: Micro Level

On the micro-level, most studies that seek to learn farmers’ behaviors in technology adoption processes use empirical approaches. For example, Adesina and Baidu-Forson focused on modern sorghum and rice varietal technologies in Burkina Faso and Guinea, two countries in West Africa, to examine how farmers’ perceptions of new agricultural technology characteristics influence their technology adoption decisions. They used an empirical model to assess the area that is cultivated in improved varieties as function of farmers’ perceptions regarding the technology as well as socio-economic and demographic factors of the farmers.

Kebede, Gunjal, and Coffin analyzed the adoption of three technologies (single-ox, pesticides and fertilizer technologies) in Ethiopia, using a logic model with various economic, social, and physical variables and degree of risk aversion. While the physical factors pertain to objective characteristics of the plots such as soil type, difficulty in plowing and so forth, the other factors are more nuanced. Economic elements for example include after-tax farm income, wealth (e.g., value of livestock and farm equipment), debt, and farm size. Social factors consist of family size, education level, exposure to outside information (captured as “index of awareness,” composed of the relative number of visits to the city and whether the farmer does or does not own a radio), farming experience etcetera. Polson and Spencer use logit and probit models to examine famers’ decisions vis-a-vis adoption of improved cassava variety in Nigeria.
Because direct observations on farmers’ perceptions of technology attributes are often not possible, such studies use variables which affect farmers’ access to information, and hence their perception formation (e.g. extension, education, media exposure, etc.). Regardless of whether studied directly observed perceptions or assessed them using proxies, findings indicate that subjective factors, beyond the physical attributes of agricultural plots and the technological offerings proposed, shape individual and group attitudes toward technology adoption.

Outside the agricultural domain, multiple studies sought to develop more theoretical approaches to investigate the adoption processes of different technologies. For instance, examining what factors influence the adoption of cell phones for financial transactions in South Africa, Brown et al. identified six factors of significance: resistance to change, exposure, relative advantage, perceived ease-of-use, perceived risk and cost. They illustrate the process under which an individual may or may not adopt cell phones for this type of use, as shown in Figure 5.2. As shown, exposure influences the level of resistance to change and both factors shape perceptions as to the technology’s relative advantage, its ease of use, risk and cost—perceptions that eventually determine the outcome of the adoption decision.

**Figure 5.2 Adoption (or Non) of Cell Phones for Financial Transactions in South Africa**

Macfarlane summarizes which issues affect adoption and implementation of new mining technology in southern Africa. Specific barriers to these processes are cited including factors associated with the technology itself (such as premature application of unproven technology; poorly engineered systems; new health and safety risks created by the technology or work system) as well as resistance to change among the workforce and supervisors stemming from a variety of reasons such as fear of job loss as a
result of the technology, and suspicion of management motives in introducing the technology. Other factors that pose a risk to successful adoption of new mining technologies are inadequate training and skill to operate the new equipment, and poor implementation, planning and control.

Technology Adoption: Macro Level

Literature on macro-level adoption of technology is scarcer but also includes empirical as well as theoretical approaches. The World Bank developed one of the most detailed macro-level approaches describing the determinants of technological progress in developing countries. Drawing on their own previous work as well as several theoretical and empirical studies, the World Bank developed a rather holistic framework for depicting the process by which countries adopt, adapt, and absorb external technologies. Specifically, the framework presents technology progress in developing countries as a process involving three main elements:

1. Exposure to high-technology business processes, products, and services through foreign trade; foreign direct investment (FDI); and contacts with diaspora and other communication channels.
2. The technological absorptive capacity of the economy, which depends on the business and macroeconomic climate, the technological literacy of the workforce, government actions designed to support financing innovative capacity, and others.
3. Increasing returns to scale and spillover effects that can magnify the absorptive impact of technological transfers.
Other researchers have also focused on a variety of factors that may influence technology adoption, but did so in a more specific manner – either in terms of the methodology used or the technology assessed. Billon et al. for example used multivariate analysis to explore which factors influence the adoption of information and communication technologies (ICT) at the country level. They found that ICT adoption patterns differ between “high achieving countries” and “developing countries.” In their distinction between countries they accounted for GDP, size of service sector, education levels, governmental effectiveness, population age, percentage of urban population and other factors.

Erumban and de Jong built an empirical model to examine how cultural aspects influence the adoption rates of ICT at the country level, using Hofstede’s cultural framework. A more thorough description of the index will be provided in Chapter 9. In a nutshell, the Index consists of five country-based cultural dimensions: inequality of the distribution of power; degree to which members of a society feel uncomfortable with uncertainty and ambiguity; sentiment of individualism; competition, ambition, and focus on performance and material value; and long-term orientation, or to what extent a culture values its traditions and how much it focuses on its past and future.
Analyzing the adoption of ICTs with a specific focus on Sub-Saharan African countries, Oyeyinka and Lal used simultaneous equation approach assessing internet diffusion, infrastructure level, and communication networks. They employed cross-country data such as GDP per capita; and telephone, personal computer use, internet use and internet hosts, as well as per capita investment on telecommunication infrastructure and enrollment in tertiary education. They developed a theoretical framework (shown in Figure 5.4) that seeks to explain a country level internet usage by its national network, which is shaped by a variety of elements including technological infrastructure (internet and telecom), human capital, investment in telecom infrastructure, and wealth (GDP).

**Figure 5.4 Cross-Country Analysis of Internet Diffusion in Sub-Saharan Africa**

![Diagram showing factors influencing internet usage](SOURCE: Oyelaran-Oyeyinka and Lal)

**Technology Adoption: Multiple Levels**

Finally, examining the adoption of internet in universities in Kenya and Nigeria, Oyelaran-Oyeyinka and Adeya offer an interesting framework that connects the micro and macro levels as shown in Figure 5.5. At the micro level, determinants of internet adoption consist of skill, disposable income, available infrastructure and so forth. At the meso level, connecting the micro with the macro, are factors related to market structure and the legal and regulatory environments. The macro level incorporates elements such as national income, national infrastructure, culture and others. The framework introduced later in Section 5.4 does not separate barriers and drivers into levels but in essence it incorporates parts from all three levels for instance farmers’ income, education and skill level, laws and regulations, national income, culture and others.
In summary, a brief literature review helped distinguish between empirical versus theoretical as well as micro- and macro-level approaches to studying technology adoption. Notwithstanding the variation of research objectives and designs, the studies reviewed indicate that factors unrelated to the technology attributes—including cultural aspects, relative education and income levels, perceptions as to a technology’s value and risks and others—shape decisions on adoption or non-adoption of technologies.

5.4. Assessing Inter-Country Variation in Likelihood of Successfully Adopting Agricultural UAS: Analytical Framework

To answer research questions 2 and 3, this study developed a novel analytical framework, as illustrated in Figure 5.6. Drawing on previous efforts to empirically study and theoretically formulate technological adoption processes, this framework incorporates various elements from both the micro- and macro-level types of studies reviewed in Section 5.3. The framework is composed of four key pillars along which countries in Africa are assessed:

1. Innovation capacity and technical literacy of the workforce (i.e., can the country successfully develop UAS technology in-house or effectively employ it if purchased from foreign suppliers; this pillar also accounts for a country’s degree of exposure to foreign technologies).
2. Affordability & Economic viability (can the country afford the technology; and what implementation models exist).


day of ICTs in Universities in Kenya and Nigeria

SOURCE: Oyelaran-Oyeyinka and Adeya. 

ICT stands for Information and Communication Technology.
3. Governance and institutional feasibility (does the country have proper governance and institutions to support investment, technology growth, human progress, etc.).
4. Cultural feasibility (to what extent is the country open/resistant to new technologies, especially “Western” and “Stigmatized.”).

Figure 5.6 Analytical Framework for Analyzing Drivers & Barriers to Agricultural UAS-Adoption

Assessments along each of the four aforementioned pillars produce a ranking of countries based on the likelihood that they successfully adopt agricultural UAS along the specific dimension examined. Subsequently, the four rankings are combined to a final likelihood-based ranking depicting the variation between countries’ holistic capacity to effectively adopt this technology. The dimension-specific rankings are weighed equally in the production of the final ranking outcome.

The framework and the subsequent chapters that explain its four elements, is concerned with 36 countries of focus in the study:

- Algeria
- Angola
- Benin
- Botswana
- Burkina Faso
- Burundi
I selected these 36 countries after carefully considering which indicators would be used to measure each pillar, and taking into consideration data availability at the country level.

5.5 Limitations of Framework

It is important to acknowledge that notwithstanding the comprehensiveness of this framework, there may be other elements that it does not cover and that influence a country’s chances of successfully adopting UAS. For example, the legal status of commercial UAS can either pose a barrier or serve as a driver in the technology’s adoption. However, data on the legality of UAS in most African countries is inaccessible, either as a result of a language barrier, or of restricted online access to legal documentation, or simply because there is legislation vacuum surrounding this issue as explained by
Kenyan government officials. Rather than attempting to examine the legal issue in each of the 36 countries of interest, the issue is introduced briefly in Chapter 2. It is plausible that African governments will adopt one of the legal regimes enacted by high-income countries with UAS capabilities such as the US, Japan, or Australia. In Kenya for example, where the government is currently in the process of drafting a law, government officials said they are using the US legal framework as a model.

Also, the four aforementioned dimensions (technical, institutional, cultural, and economic feasibility) may not be entirely independent for one another. Also, they are not hierarchical in importance. Rather, multiple factors embedded in each of these dimensions are required for successful adoption of UAS. Conversely, absence of such factors may hinder the adoption of this technology. Nevertheless, for analytical simplicity it is assumed that the five dimensions are standalone.

Finally, the contribution of the four dimensions to a country’s capacity to adopt new technologies may not be equal, as demonstrated by the example of Egypt, a country with UAS capabilities. On the one hand, Egypt’s average GDP per capita in 2010–2014 was $3,314.5 versus the global average of $10,613.5. Also, it is ranked low on many governance indicators (around 20th percentile in government effectiveness, voice and accountability and regulatory environment and 10th percentile in political stability), as well as in terms of cultural openness to new technology. At the same time, according to the framework, Egypt has the highest technical feasibility score of all 36 countries examined which may explain its present UAS capabilities.

Nevertheless, because the influence of these and other elements is context dependent and cannot be generalizable to 36 countries in Africa, the framework uses equal weighing of the four dimensions to generate the final likelihood-based ranking. This approach is also consistent with strategies used in similar indices; it is simple; and transparent. In addition, despite limitations, the innovative approach to such ranking of countries will help identify inter-country variation in the likelihood to successfully adopt UAS for agriculture. Further, it will indicate along which dimensions countries’ capacity to adopt this technology is lacking. Finally, it will inform the development of concrete recommendations for policymakers interested in promoting this technology in Africa.
Chapter 6: Innovation Capacity & Technical Literacy of Workforce

6.1. Introduction

The first stage in the framework developed to assess the likelihood that a country may or may not be able to successfully adopt agricultural UAS technology is technical feasibility assessment. Due to lack of research on adoption of civilian UAS technology, this assessment draws on literature on military UAS diffusion which differentiates between countries’ capabilities to develop UAS in-house, import UAS and employ the technologically effectively. Accordingly, the technical feasibility assessment conducted in this chapter seeks to answer the following questions:

1. Can a country develop UAS?
2. Can a country import UAS?
3. Can a country effectively use UAS?

The premise of this three-part objective is that development of UAS requires high technical capabilities which most countries in the world currently do not have. Still, if a country is found technically incapable of developing UAS in-house, it may still be able to import this technology, a prospect that depends primarily on the country’s global standing and on restrictions imposed by UAS-exporting countries. Finally, even if a country is well-positioned both in the international arena and economically, and can purchase this technology, it may not be capable of operating it effectively due to insufficient technical skill.

The rest of the chapter is organized as follows. Section 6.2 briefly discusses the motivation of countries seeking to obtain UAS capabilities. Section 6.3 seeks to answer the questions ‘can a country develop UAS?’ Section 6.4 discusses the non-economic factors that determine a country’s ability to import UAS technology. Section 6.5 explores whether a country can effectively employ UAS. Each of sections 6.3–6.5 includes a literature review, introduction of the data utilized, the methodology used, and the findings generated by the analysis. Section 6.6 combines the findings from these sections and concludes this chapter.

6.2 Countries’ Motivations for Pursuing UAS Capabilities

Literature on the demand side of military UAS markets is concerned with understanding why countries seek to obtain UAS capabilities. The question why a country may or may not wish to obtain agricultural UAS capabilities is beyond the scope of this study. Instead, the study adopts conclusions of studies in the area of military UAS according to which countries seek such technology either (1) since they have demonstrated need for it; or (2) because they seek prestige on the global map.

First, this study assumes that a strong need may motivate countries, or farmers in countries, to seek agricultural UAS technology. Part I of the study demonstrated that numerous African countries face
some major agricultural issues for which UAS may provide a solution; thus they may need such technology. This “need-based” assumption relies on one of the most popular explanations for why countries pursue military UAS, or drones—because they may need this technology. As in the general case of military innovations, countries are more likely to develop UAS if they face a threatening security environment, primarily territorial disputes and terrorist and insurgent threats. The reasoning is that UAS offer several benefits over manned aircraft that justify their pursuit, including strike and surveillance capabilities, safety for aircrew, improved situational awareness, and potential cost-savings. For similar reasons, international organizations may acquire UAS technology. In the context of Africa, this argument can explain why Ethiopia’s sought to employ UAS in its counterterrorism efforts against Eritrea-backed rebels and Somalia’s al-Shabab terrorists (who are linked with al-Qaeda). Similarly, an international organization or aid agency may wish to employ agricultural UAS in the event that this technology is suitable to overcome a pressing challenge in a country of interest.

However, security needs alone fail to fully explain a country’s decision to gain or not to gain UAS capabilities. Data suggests that 82 percent of countries that recently experienced terrorism do not have UAS capabilities. This does not mean that a country does not wish to obtain such capabilities but rather that military UAS are still costly, or that they raise other security concerns that offset their projected advantages. Such concerns are primarily in the information security domain—UAS are relatively vulnerable to hacking and the data links may be generally disrupted, making them possibly less reliable. Moreover, as will be discussed in more detail in Chapter 10. Cultural Feasibility, UAS may face public resistance which could limit their diffusion. At the same time, countries that are neither mired in territorial conflict nor faced with terrorist threats also seek to procure military UAS.

The second prominent reasoning for why a country may seek military drones, or any other advance weapon system, is their pursuit of prestige. Several studies have found that status can motivate the acquisition of new military capabilities even more than the security environment. Horowitz and Fuhrmann find that countries seeking to enhance their international status are more likely to operate tactical UAS. In Africa, Nigeria is used as an example of such a country. Similarly, countries may seek civilian, including agricultural, UAS capabilities as an indication of progression and development.

Other explanations have been proposed throughout the years to explain diffusion of military technologies, including potentially UAS. However, the need-based and prestige-seeking theories have gained most traction. Assuming the demand exists, this chapter will discuss the factors that make countries suitable for production or employment of UAS. From the supply side, it will introduce general export regulations which can limit the import of UAS technology even given demand and ample technical skill.
6.3 Assessing African Countries’ Capacity to Develop UAS In-House

6.3.1 Background & Literature Review

Literature on military technological innovation diffusion suggests that a country’s adoption of advanced technologies depends on its technical capabilities and/or its ability to secure foreign assistance. From a pure technical perspective, UAS’ dual-use nature increases the likelihood of their spread globally. Dual-use technologies, like computer and software capabilities, are not capital intensive thus pose minor entry barriers to newcomers.\textsuperscript{ccclxxxiii} This implies that many countries with advanced information economies have the capacity to build their own UAS. Indeed, some experts predict that in similar to nuclear energy,\textsuperscript{ccclxxxiv} numerous countries will be able to develop advanced UAS over the next decade.\textsuperscript{ccclxxxv}

Moreover, a growing number of scholars from the discipline of International Relations (IR) project that UAS are likely to proliferate because they are relatively simple and inexpensive. In the general case, military technologies, and particularly hardware, are considered to spread easily, especially in light of both globalization and the information revolution processes which.\textsuperscript{ccclxxxvi} Therefore, according to such IR scholars, less developed countries can leverage on their high rates of economic growth and diffusion of technical knowledge to gradually build advanced military technologies.\textsuperscript{ccclxxxvii}

Notwithstanding important examples in the history of military technologies, this view is deemed simplistic in the eyes of other researchers who argue that IR theorists downplay the technological challenges, as well as the infrastructure requirements, necessary to develop military UAS. And while the suggested agricultural UAS discussed in Chapters 2–4 are expected to be less sophisticated than superior military equivalents, the development of military and civilian UAS shares common characteristics. Further, through multivariate analysis, Horowitz and Fuhrman find that technological capacity is important for explaining the proliferation of even unsophisticated UAS.\textsuperscript{ccclxxxviii}

To understand the specifics of this technological capacity, it is useful to review some broad classifications of UAS. Beyond the traditional classification by performance and characteristics, which was covered in Chapter 2, the literature on adoption of military UAS distinguishes between different types of systems according to their function and capabilities. One distinction is between armed and unarmed, and advanced and tactical UAS. While the difference between armed and unarmed is clear, “advanced” UAS “employ cutting-edge technology, have significant loitering capabilities, and can operate over the horizon.” Tactical UAS on the other hand utilize less sophisticated technology and are used for short-range missions.\textsuperscript{ccclxxxix} Another useful distinction is between three types of military UAS: loitering attack munitions (LAMs) and unmanned combat aerial systems (UCAS), under armed and advanced UAS; and intelligence, surveillance and reconnaissance (ISR) under unarmed and either tactical or advanced UAS.\textsuperscript{cccxc}

The capabilities required to manufacture each of these types of UAS are different. For example, the production of combat-effective UAS is most challenging. It requires sophisticated knowledge in design,
development and manufacturing that would enable the integration of different systems (e.g. engine, communication system, etc.), subsystems (antenna, expendable modules like missiles, etc.) and components (circuits, sensors, etc.) together and ensuring their compatibility, reliability and proper interaction, while maximizing the platform’s performance. Using the examples of Germany and the UK which face difficulties in developing such UAS, Gilli and Gilli argue that less developed countries may face even more formidable barriers to their development.

Further, they contend that even if globalization has increased access to some technological components needed to manufacture UAS, the integration process of these elements still casts major technological challenges. An often-cited example in this context is Apple’s iPhone. Even though it relies extensively on commercial components, only few imitators have developed comparable alternatives to the iPhone after significant delays and problems. Specifically in the case of ISR UAS, the commercial availability of some key components is still insufficient to effectively build military UAS. In addition, as will be discussed in more length in subsequent sections on whether countries can import and effectively operate UAS, adoption of UAS technology from a technical perspective depends also on the availability of infrastructure (such as communication systems and ground facilities), as well as ICT-skilled personnel.

These technological challenges are not constant across countries but depend on the domestic know-how, infrastructure and prior experience of countries in relevant sectors. Wealthier and more advanced countries are generally favored since they can take advantage of their larger available resources, past experience and existing expertise to produce UAS. Naturally, developing countries are lagging behind.

Literature on the technical requirements for production of civilian UAS is scarce. Therefore, to understand the competencies required of African countries to produce agricultural UAS; this study alludes to those pertaining to ISR UAS, which are not necessarily easily produced. As evidence, several European countries, Turkey and India have attempted at developing their own MALE ISR programs but have faced tremendous difficulties. Nevertheless, of all their peers, ISR UAS (and especially tactical ones) are mostly similar to civilian UAS. The main reason is that both UAS types rely extensively on commercial or dual-use technologies, such as communication systems, light electric engines and electro-optical sensors.

Indeed, as some scholars argue, many actors can theoretically obtain ISR capabilities through open-source systems (e.g., Google Maps) as well as through access to communication and observations satellites. Yet, production of ISR UAS still requires sophisticated capabilities in the following disciplines:

- Aeronautical and mechanical engineering;
- Materials;
- Electronics;
- Computers;
- Software;
Undeniably, agricultural UAS which may tackle some of the African challenges discussed in Chapters 2–4 are expected to be less sophisticated than military ISR UAS. However, some of those UAS may still require a certain level of technological superiority. For example, the VTOLs suggested for eradicating the Tsetse fly are relatively large platforms that can carry a payload of over 150 lb. and by no means are considered simple to manufacture. Thus, although the production of agricultural UAS may pose less strict technical requirements than of military ones, this study employs a conservative approach. Accordingly, it assumes that only countries with expertise in the aforementioned disciplinary areas—and of course those with traditional aerospace know-how and industrial base—are capable of successfully producing agricultural UAS in-house.

6.3.2 Data, Methodology & Findings

This sub-section describes the different types of data utilized and methodology developed to address the question which countries in Africa are more likely to be able to develop UAS? It concludes with the results of the analysis and an answer to this question.

Data

UAS are considered an innovative technology. Further, a country’s ability to develop UAS technology in-house is contingent upon its innovative capacity. Thus, the study uses the Global Innovation Index (GII), which ranks countries’ technological innovation—and technical—capabilities. The GII “includes indicators that go beyond the traditional measures of innovation such as the level of research and development.” The index, which covers the 36 African countries of interest in this study, is composed of two sub-indices, the Innovation Input Sub-Index and the Innovation Output Sub-Index, each built around pillars, as shown in Figure 6.1.
Figure 6.1 Global Innovation Index (GII)
The input pillars capture elements of national economies that enable innovative activities: Institutions; Human capital and research; Infrastructure; Market sophistication; and Business sophistication. The output pillars measure evidence of innovation outputs: Knowledge and technology outputs; and Creative outputs. The Innovation Output sub-index is especially important as it captures technology transmission channels into a country. This component is crucial because the domestic pace of technological progress within developing countries is determined mainly by the speed with which existing technologies are adopted, adapted and successfully applied domestically. Thus, the ability to account for a country’s exposure to foreign technology—by measuring its trade in high technology goods and services and FDI—makes the GII particularly useful for this assessment.

Each pillar in the GII is divided into sub-pillars and each sub-pillar is composed of individual indicators (81 in total). Sub-pillar scores are calculated as the weighted average of individual indicators; pillar scores are calculated as the weighted average of sub-pillar scores.

While the GII is helpful in assessing a country’s general technological capabilities, it is not UAS-specific. To analyze specifically the innovation capacity of African countries in the context of UAS technology, this chapter also employs a proxy for a country’s ability to produce UAS-specific knowledge. This proxy is the number of academic publications per country in the relevant disciplines which were identified previously for production of effective UAS (aeronautical & mechanical engineering; materials; electronics; computers; software; communications; propulsion; and operations).

Publications were retrieved from Web of Science, an academic citation indexing and search service which spans across all scientific disciplines published in English as well as in foreign-language publications.

**Methodology**

Initially, the GII was modified to assess a country’s capability of producing UAS in-house. Five of the seven pillars of the GII are useful for this task:

- Human capital and research;
- infrastructure;
- business sophistication,
- knowledge and technology outputs;
- and creative outputs.

Substitutes for the institutions pillars will be employed in Chapter 8, which covers the governance and institutional feasibility dimension. Market sophistication is not as relevant for analyzing whether a country has the technical ability to develop, import or operate UAS. However, an equivalent element is included in measures of the business environment that are also captured in Chapter 8.

All sub-pillars corresponding to the five pillars comprising the modified GII have been included except for ecological sustainability which is unrelated to the technical feasibility stage. The modified GII used is presented in Figure 6.2.
Detailed breakdown of pillars and sub-pillars into indicators and the area in which they will be used in the analytical framework to assess the feasibility of adopting UAS technology in Africa is included as Appendix F.

Subsequently, data were collected on the 36 countries of interest (which are also the only African countries covered by the GII), as shown in Appendix G. New input score and the new output score for every country were calculated and combined to produce a modified GII score. Countries were ranked accordingly as shown in Figure 6.3.
Notwithstanding its usefulness for assessing countries’ general technical and technological innovation capabilities, even in its modified form the GII is general and not UAS-specific. Thus, the modified GII was scaled by the number of academic publications per country in the relevant disciplines required for UAS production, as mentioned above. The number of publications serves as a proxy for a country’s advanced knowledge in relevant fields, as listed earlier as well as in Table 6.1.
Table 6.1 Web of Science Categories & Connection to Required Disciplinary Knowledge for UAS

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<tr>
<th>Web of Science Category</th>
<th>Disciplinary knowledge - UAS</th>
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<tr>
<td>Automation &amp; Control Systems</td>
<td>Operations</td>
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<td>Engineering, Industrial</td>
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<td>Imaging Science &amp; Photographic Technology</td>
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<td>Remote Sensing</td>
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<td>Computer Science, Artificial Intelligence</td>
<td>Computers &amp; Software</td>
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<td>Computer Science, Cybernetics</td>
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<td>Computer Science, Hardware &amp; Architecture</td>
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<td>Computer Science, Information Systems</td>
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<td>Computer Science, Software Engineering</td>
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<td>Engineering, Manufacturing</td>
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<td>Materials Science, Ceramics</td>
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<td>Materials Science, Characterization &amp; Testing</td>
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<td>Materials Science, Coatings &amp; Films</td>
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</tbody>
</table>

Web of Science was used for the search of publications. Appendix H lists the different scientific categories used by Web of Science. Having identified the disciplinary knowledge required for UAS production, searches were conducted in corresponding Web of Science categories, as shown in Table 6.1.

The search sought to capture all categories for all 36 African countries. Moreover, the search was performed in all languages, and was not restricted to any particular document type, or to any timeframe. Perhaps unsurprisingly, in most countries, except for South Africa, publications in these
disciplines are uncommon. Appendix I presents the results of search by country and by category. Figure 6.4 shows the total number of publications in all relevant disciplines by country. The results demonstrate clearly that six countries have significantly more publications in those fields than other countries in Africa—Egypt, South Africa, Algeria, Tunisia, Morocco and Nigeria.

Figure 6.4 Publications in Disciplines Required for UAS Production, by Country

For each of the six countries leading in the number of relevant publications, Table 6.2 breaks down their publication frequencies by the disciplines in which knowledge is required for UAS production. In addition to the absolute numbers, the table depicts the relative proportion of publications per discipline as percentage of the total relevant publications for each country. Clearly, all six countries produce relatively more publications in the areas of materials, electronics, and computers & software. The most developed nation in Africa, South Africa, also publishes relatively more than the others in the field of power. Nigeria is an exception with 18 percent of its publications being in the area of propulsion in comparison of around 10 percent for the others. All countries seem to produce less advanced knowledge in mechanical and aeronautical engineering. Nevertheless, this breakdown is useful in showing that these six countries not only have expertise in one of the disciplines required for UAS production.
Table 6.2 Publication Breakdown per Discipline per Country

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Egypt</th>
<th>South Africa</th>
<th>Algeria</th>
<th>Tunisia</th>
<th>Morocco</th>
<th>Nigeria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>9550 (26.8%)</td>
<td>4704 (18.1%)</td>
<td>3681 (24.1%)</td>
<td>3032 (20.1%)</td>
<td>2293 (30.8%)</td>
<td>1235 (24.6%)</td>
</tr>
<tr>
<td>Electronics</td>
<td>7327 (20.5%)</td>
<td>4816 (18.6%)</td>
<td>3469 (22.7%)</td>
<td>3525 (23.4%)</td>
<td>1320 (17.7%)</td>
<td>439 (8.8%)</td>
</tr>
<tr>
<td>Computers &amp; Software</td>
<td>4905 (13.7%)</td>
<td>4993 (30.4%)</td>
<td>2577 (16.9%)</td>
<td>3362 (22.3%)</td>
<td>1317 (17.7%)</td>
<td>486 (14.6%)</td>
</tr>
<tr>
<td>Power</td>
<td>3696 (10.4%)</td>
<td>2464 (19.3%)</td>
<td>1296 (8.5%)</td>
<td>952 (6.3%)</td>
<td>715 (9.6%)</td>
<td>1062 (9.7%)</td>
</tr>
<tr>
<td>Propulsion</td>
<td>3687 (10.3%)</td>
<td>3438 (13.2%)</td>
<td>1324 (8%)</td>
<td>1052 (7%)</td>
<td>464 (6.2%)</td>
<td>918 (18.3%)</td>
</tr>
<tr>
<td>Operation</td>
<td>2344 (6.5%)</td>
<td>2235 (8.6%)</td>
<td>1282 (8.4%)</td>
<td>1399 (9.3%)</td>
<td>617 (8.3%)</td>
<td>321 (6.4%)</td>
</tr>
<tr>
<td>Communications</td>
<td>2006 (5.6%)</td>
<td>1316 (5%)</td>
<td>716 (4.7%)</td>
<td>1114 (7.4%)</td>
<td>348 (4.7%)</td>
<td>92 (1.8%)</td>
</tr>
<tr>
<td>Mechanical Engineering</td>
<td>1916 (5.3%)</td>
<td>1672 (6.4%)</td>
<td>812 (5.3%)</td>
<td>613 (4%)</td>
<td>343 (4.6%)</td>
<td>422 (8.4%)</td>
</tr>
<tr>
<td>Aeronautical Engineering</td>
<td>196 (0.55%)</td>
<td>264 (1%)</td>
<td>81 (0.5%)</td>
<td>16 (0.1%)</td>
<td>16 (0.2%)</td>
<td>30 (0.6%)</td>
</tr>
<tr>
<td>Total</td>
<td>35627</td>
<td>25902</td>
<td>15238</td>
<td>15065</td>
<td>7433</td>
<td>5005</td>
</tr>
</tbody>
</table>

* Percentages in each column may not add to 100% as result of rounding errors.

The results of the publication count (total) were multiplied by the modified GII score to produce a technical feasibility score specific to countries’ innovative capacity to produce UAS technology.

Findings
Scaling the modified GII scores by the publication count resulted in a technical feasibility ranking of the 36 African countries, as presented in Table 6.3. Figure 6.5 graphs the results according to technical feasibility score.
### Table 6.3 Ranking of African Countries by Technical Feasibility Score

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Country</th>
<th>Modified GII</th>
<th>Publications</th>
<th>Proportion</th>
<th>Tech. Feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Egypt</td>
<td>384.6</td>
<td>35627</td>
<td>0.3218</td>
<td>123.7705653</td>
</tr>
<tr>
<td>2</td>
<td>South Africa</td>
<td>397.9</td>
<td>25902</td>
<td>0.2340</td>
<td>93.09708417</td>
</tr>
<tr>
<td>3</td>
<td>Tunisia</td>
<td>397.4</td>
<td>15065</td>
<td>0.1361</td>
<td>54.07864976</td>
</tr>
<tr>
<td>4</td>
<td>Algeria</td>
<td>286.8</td>
<td>15238</td>
<td>0.1376</td>
<td>39.47625603</td>
</tr>
<tr>
<td>5</td>
<td>Morocco</td>
<td>373.7</td>
<td>7433</td>
<td>0.0671</td>
<td>25.09089029</td>
</tr>
<tr>
<td>6</td>
<td>Nigeria</td>
<td>284.2</td>
<td>5005</td>
<td>0.0452</td>
<td>12.84863512</td>
</tr>
<tr>
<td>7</td>
<td>Kenya</td>
<td>332.5</td>
<td>716</td>
<td>0.0665</td>
<td>2.150470616</td>
</tr>
<tr>
<td>8</td>
<td>Cameroon</td>
<td>283.8</td>
<td>684</td>
<td>0.0062</td>
<td>1.75346937</td>
</tr>
<tr>
<td>9</td>
<td>Mauritius</td>
<td>435.1</td>
<td>410</td>
<td>0.0037</td>
<td>1.61139413</td>
</tr>
<tr>
<td>10</td>
<td>Ghana</td>
<td>340.8</td>
<td>475</td>
<td>0.0043</td>
<td>1.462251368</td>
</tr>
<tr>
<td>11</td>
<td>Tanzania, United Rep.</td>
<td>283.3</td>
<td>537</td>
<td>0.0049</td>
<td>1.37419923</td>
</tr>
<tr>
<td>12</td>
<td>Senegal</td>
<td>313.7</td>
<td>398</td>
<td>0.0036</td>
<td>1.127785305</td>
</tr>
<tr>
<td>13</td>
<td>Botswana</td>
<td>320</td>
<td>381</td>
<td>0.0034</td>
<td>1.101295322</td>
</tr>
<tr>
<td>14</td>
<td>Ethiopia</td>
<td>273.3</td>
<td>399</td>
<td>0.0036</td>
<td>0.985011652</td>
</tr>
<tr>
<td>15</td>
<td>Zimbabwe</td>
<td>274.9</td>
<td>364</td>
<td>0.0033</td>
<td>0.903867902</td>
</tr>
<tr>
<td>16</td>
<td>Uganda</td>
<td>350.6</td>
<td>228</td>
<td>0.0021</td>
<td>0.722063845</td>
</tr>
<tr>
<td>17</td>
<td>Burkina Faso</td>
<td>293.5</td>
<td>183</td>
<td>0.0017</td>
<td>0.485163406</td>
</tr>
<tr>
<td>18</td>
<td>Zambia</td>
<td>232.1</td>
<td>145</td>
<td>0.0013</td>
<td>0.30399888</td>
</tr>
<tr>
<td>19</td>
<td>Malawi</td>
<td>305.5</td>
<td>105</td>
<td>0.0009</td>
<td>0.289753943</td>
</tr>
<tr>
<td>20</td>
<td>Guinea</td>
<td>208.2</td>
<td>147</td>
<td>0.0013</td>
<td>0.276456561</td>
</tr>
<tr>
<td>21</td>
<td>Madagascar</td>
<td>265.6</td>
<td>113</td>
<td>0.0010</td>
<td>0.271103644</td>
</tr>
<tr>
<td>22</td>
<td>Mozambique</td>
<td>343.6</td>
<td>76</td>
<td>0.0007</td>
<td>0.235882427</td>
</tr>
<tr>
<td>23</td>
<td>Niger</td>
<td>278</td>
<td>80</td>
<td>0.0007</td>
<td>0.200892454</td>
</tr>
<tr>
<td>24</td>
<td>Rwanda</td>
<td>309</td>
<td>69</td>
<td>0.0006</td>
<td>0.192591187</td>
</tr>
<tr>
<td>25</td>
<td>Namibia</td>
<td>279.6</td>
<td>74</td>
<td>0.0007</td>
<td>0.186895019</td>
</tr>
<tr>
<td>26</td>
<td>Lesotho</td>
<td>313.5</td>
<td>51</td>
<td>0.0005</td>
<td>0.144423067</td>
</tr>
<tr>
<td>27</td>
<td>Benin</td>
<td>253.6</td>
<td>61</td>
<td>0.0006</td>
<td>0.139735877</td>
</tr>
<tr>
<td>28</td>
<td>Mali</td>
<td>273.7</td>
<td>53</td>
<td>0.0005</td>
<td>0.131032645</td>
</tr>
<tr>
<td>29</td>
<td>Swaziland</td>
<td>266.2</td>
<td>51</td>
<td>0.0005</td>
<td>0.12263292</td>
</tr>
<tr>
<td>30</td>
<td>Angola</td>
<td>233.5</td>
<td>51</td>
<td>0.0005</td>
<td>0.107568695</td>
</tr>
<tr>
<td>31</td>
<td>Togo</td>
<td>179.3</td>
<td>49</td>
<td>0.0004</td>
<td>0.079360649</td>
</tr>
<tr>
<td>32</td>
<td>Seychelles</td>
<td>443.2</td>
<td>14</td>
<td>0.0001</td>
<td>0.056047549</td>
</tr>
<tr>
<td>33</td>
<td>Gambia</td>
<td>316.6</td>
<td>13</td>
<td>0.0001</td>
<td>0.03717775</td>
</tr>
<tr>
<td>34</td>
<td>Burundi</td>
<td>214.8</td>
<td>13</td>
<td>0.0001</td>
<td>0.025223565</td>
</tr>
<tr>
<td>35</td>
<td>Cabo Verde</td>
<td>335.7</td>
<td>0</td>
<td>0.0000</td>
<td>0</td>
</tr>
<tr>
<td>36</td>
<td>Côte d'Ivoire</td>
<td>272.6</td>
<td>0</td>
<td>0.0000</td>
<td>0</td>
</tr>
</tbody>
</table>
As shown in Figure 6.5, the same six countries that were found to produce more academic publications in relevant disciplines for UAS-production are also the countries with the highest technical feasibility scores. These countries are Egypt, South Africa, Tunisia, Algeria, Morocco and Nigeria. Higher feasibility score implies greater likelihood to produce UAS domestically. This finding is not surprising considering how skewed publication differentials are toward the six countries mentioned above.

6.4 Assessing a Country’s Ability to Import UAS Technology

6.4.1 Background

The international UAS marketplace gives countries without the capacity to build their own UAS the ability to purchase them from abroad. Indeed, most states with UAS imported them from foreign suppliers. Nevertheless, the markets for military technologies have been traditionally politicized, and the UAS market is no different. Military alliances govern such markets as countries are usually more inclined to share military technologies with their allies than with their non-allies. The degree of alliance that determines whether a UAS manufacturer will sell the technology to another country varies between countries. The USA, one of the three main producers of UAS, has stringent export restrictions on UAS. It has exported some advanced UAS to close allies in a very limited manner, and sold an armed UAS only to the UK.

On the other hand, Israel and China, the other two leading UAS producers, are considered prominent exporters of military technology. Israel is especially a world leader in the area of UAS.
Arms Trade Register of the Stockholm International Peace Research Institute, Israel has thus far exported military UAS to 49 states around the world. China, on the other hand, has reportedly already exported an armed UAS to the UAE and intends to export armed UAS to Saudi Arabia and Pakistan. This is not to say that Israeli and Chinese UAS exports have been divorced from their international interests but rather that they may be less discriminative in this market. New data shows that countries that have military alliances with the USA, Israel and China, are more likely than other countries to have tactical and advanced UAS.

6.4.2 Data, Methodology & Findings

Data & Methodology
To assess countries’ ability to import UAS, this study utilized open source data on US export regulations, as governed by the US Department of State and the US Department of Commerce, and the two most important multilateral export control regimes that address UAS—the Missile Technology Control Regime (MTCR) and Wassenaar. It is important to note that neither Israel nor China—two of the prominent UAS exporters—are members in these regimes, although Israel has elevated the importance of export restrictions since 2006 and follows some of the MTCR guidelines on technologies, as explained below.

This assessment does not consider a country’s financial ability to purchase UAS from foreign sources because it is not a necessary determinant of a country’s innovation capacity and technical literacy of the workforce. Whether a country can afford to import UAS technology is covered in Chapter 7. Further, as next chapter will discuss, a country’s wealth may be less pertinent when examining the feasibility of adopting agricultural UAS with the aim of boosting domestic food production and improve food security. Instead, international organization may subsidize or fund such UAS-based programs even in poor countries that cannot afford them, for example, the SIT release program in Senegal funded by the FAO.

US Export Regulations
Very few countries are under strict US embargo (e.g., North Korea, Cuba, Iran), none of which are located in Africa. Hence, theoretically, all African countries may be able to import UAS technology from the USA (or some ally members of the export control regimes since they consult each other on such matters). These include the African countries examined in this study—all 37 countries covered by GII, looking particularly at the 31 countries found here as currently less likely to be capable of producing UAS domestically.

The prospect of exporting (and African countries’ ability to import) UAS technology depends on several laws which authorize the sale or transfer of export controlled technologies, including dual use ones, from the United States (companies or the government) to foreign countries, or foreign entities. These laws include for instance the Arms Export Control Act of 1976, the Export Administration Act of 1979, and others. Exporting both armed and unarmed UAS is governed by these laws.
US entities wishing to sell abroad UAS, or, any other export-controlled technology as a matter of fact need to apply for special export licenses. The receipt of such a license depends on the technology type and the country or entity involved. Specifically, it depends on the extent to which such a sale raises concern with respect to the following reasons: proliferation of chemical and biological weapons; nuclear proliferation; national security; spread of missile technology; firearms; regional stability; crime; and terrorism.

For each technology, the licenses required hinge on the number and types of concern or “reason for control.” It is assumed in this study that the more reasons for control, the harder it is likely to be to obtain an export license. Figure 6.6 is taken directly from the Department of Commerce’s regulations on export-controlled technology and depicts the “reason for control” system, by country. As shown on this page for example, Algeria and Angola, the only African countries captured here, raise ten reasons each for control versus four only for Australia, a major US ally and security partner.

**Figure 6.6 Export Restrictions on Unarmed UAS**


South Africa, itself an exporter of UAS technology, raises nine reasons for control. For reference, Canada is associated with two reasons only and Israel and Iraq with 12 each. The number of reasons is used in this study to assess the ability of countries to import UAS from the United States (or one of its allies that is signatory to MTCR and/or Wassenaar). It is assumed that the number of reasons correlate negatively with the likelihood of importing the technology.

**Multilateral Export Regimes That Address UAS**

The two key multilateral regimes that address exports of UAS are the MTCR and Wassenaar. MTCR, established in 1987, is a voluntary association of 34 countries that share the goal of limiting the spread
of ballistic and cruise missiles and UAS capable of delivering weapons of mass destruction. Wassenaar, established in 1996, is a voluntary association of 41 countries that share the goal of limiting the spread of certain conventional weapons and sensitive dual-use items having both civilian and military applications.\textsuperscript{cxxxviii}

Both are consensus-based, requiring that all members must agree to any proposed changes in regime documents or activities. In both instances, members agree to restrict exports of sensitive technologies by placing them on commonly agreed to lists and incorporating these lists into their national export control laws and regulations. Members also conduct activities in support of the regimes, such as sharing information about denied license applications and conducting outreach to countries that are not members of the regimes. MTCR members have a “no undercut” policy for all MTCR-controlled items, meaning that they consult with each other before considering exporting an item on the list. Therefore, it is assumed in this study that if the United States refuses to sell UAS technology to a certain country, the other members will not sell it either. That of course does not apply to the non-members Israel and China.

\textit{Israeli Export Restrictions}

In examining information-sharing and cooperation on UAS exports, the Government Accountability Office (GAO) interviewed Israeli export control officials. Israel was selected because it is a major UAS producer and exporter and also because it has changed its export rules relatively recently. This account is based on the GAO’s findings\textsuperscript{cdxix}.

As of 2006, Israel has amended legislation that elevated the importance of export controls in several ways, including setting requirements for Israeli exporters to register before applying for any export control license, establishing periodic reporting, record-keeping, and inspection requirements; providing for new penalties and so forth. In addition, lists of controlled technologies were generated based on MTCR and Wassenaar munitions and dual-use lists. Even though not a member in either regime, Israeli officials meet regularly with MTCR and Wassenaar Arrangement officials. In addition, Israeli officials meet with export control counterparts from the USA, UK, Germany, and other countries. With respect to license applications involving UAS technology, according to Israeli officials, the country typically imposes licensing conditions similar to those enforced by MTCR members. This does not imply that Israel adheres to either regime however that it may have limited its exports recently. However, it may indicate that a refusal by the United States or one of the export control regime members to export UAs to a country will not be readily substituted for an Israeli approval as often thought.\textsuperscript{cxxx}

\textbf{Findings}

Throughout the review of the full export restriction documentation on export of unarmed UAS by US entities, it was found that for the vast majority of African countries, there are ten reasons for export control of unarmed UAS. The exceptions to this rule are Rwanda with 11 reasons, and Libya, Sudan and Egypt with 12 each. Egypt’s example illustrates why export restrictions are a sub-optimal proxy for assessing a country’s ability to import UAS technology. Despite multiple security threats, Egypt in fact
already has military UAS capability.\textsuperscript{cdxxi} Also, as demonstrated earlier in this chapter, Egypt is found likely to be capable of producing UAS in-house based on the level of its innovation capacity.

What is the source of this contradiction? It is speculated that Egypt’s internal turmoil and turbulent surrounding explain the concerns associated with selling it military and dual-use technologies. On the other hand, the country’s critical role in the Middle East, its reliance on US security assistance, as well as its alliance with Israel, helps explain why despite a larger-than-average number of reasons for control, Egypt possesses the technology. Thus, while export restrictions are important, by no means are they a perfect measure of a country’s ability to import UAS should it wish and afford to do so (either independently or as in the case of Egypt, through military aid).

In assessing the ability of all 36 African counties of interest to import UAS based on UAS export regimes, all seem to have an equal chance of doing so except for Rwanda, which has a lower likelihood. Rwanda in turn is not treated here as incapable of importing UAS however the likelihood that it succeeds is lower. Egypt is theoretically also less likely to import UAS however since it is known to already have this technological capacity, its ability to import it is of less importance in this study. In addition, based on the export restrictions analysis, South Africa can more easily purchase UAS from foreign suppliers. Yet, the country is already an independent exporter of this technology making this finding irrelevant.

6.5 Assessing a Country’s Ability to Effectively Employ UAS Technology

A country’s global standing (and national wealth) may indeed enable it to import UAS technology. However, it may not be capable of operating it effectively due to insufficient technical skill. The objective is this sub-section is to assess the technical literacy of African countries as proxy for their ability to effectively employ UAS technology.

6.5.1 Background & Literature Review

The international UAS marketplace gives countries without the capacity to build their own UAS the ability to purchase them from abroad. Importing UAS however does not entirely eliminate technological hurdles as questions remain regarding a country’s ability to effectively employ the UAS technology. Drawing primarily from literature on military UAS, these hurdles are twofold: UAS need supporting infrastructure, and their operation requires technologically-savvy workforce.

In terms of infrastructure, military UAS are not stand-alone platforms but rather they require sophisticated supporting infrastructures including data-link, communication relays and ground control stations.\textsuperscript{cdxxii} Building such infrastructure is estimated as too complicated and costly for many countries around the world.\textsuperscript{cdxxiii} Thus, a prerequisite for operating military UAS can is a technological base. Colombia for instance has had the means to purchase a military UAS from Israel but has struggled to operate it.\textsuperscript{cdxxiv}
Using national wealth as proxy for technological capacity, Horowitz and Fuhrmann find that wealthy\(^{15}\) countries are far more likely than non-wealthy ones to have tactical, advanced and armed UAS. This does not imply that non-wealthy countries cannot operate UAS, as suggested by the examples of India, Iran, and Malaysia—all considered developing countries—which have developed advanced UAS in-house.\(^{cdxxv}\) Yet, this prospect is more likely in the case of developed states. In addition, successful adoption of UAS technology depends also on the technical skill of the workforce.\(^{cdxxvi}\)

This insight is consistent with literature on the influence that human capital has on ICT adoption. Human capital disparities, as measured by years of schooling, are important in contributing to the global digital divide. Differences in education explain from 9.9 to 14.4% of the gaps in computer penetration rates.\(^{cdxxvii}\) Computers apparently require substantial levels of education for use, limiting demand in countries with relatively low levels of human. Thus, even after controlling for differences in income, human capital disparities are important in creating a global digital divide.\(^{cdxxviii}\)

Indeed, the literature on employment of military UAS suggests that the requirements for using UAS are less demanding than those to developing this technology in-house. Further, operating the agricultural UAS discussed in this study is expected to require less technical skill than military UAS. Yet, in similar to computers, a certain degree of technological skill is required even for the use of unsophisticated UAS. Therefore, in analyzing whether a country can effectively operate UAS, this study considers the level of its human capital by using education as proxy.

### 6.5.2 Data, Methodology & Findings

**Data**

As indicated, successful adoption of UAS technology depends on the technical skill of the workforce.\(^{cdxxix}\) While operating agricultural UAS may not necessitate higher education, it still requires literacy, ability to understand communication and navigation constraints and more. Thus, to examine whether countries less likely to be capable of developing UAS, but that can theoretically import this technology, are capable of effectively employing it, this chapter uses education level and prevalence as proxy. Specifically, it utilizes tertiary education indicator, one of the three key elements that comprise the Human Capital and Research pillar of the GII.

Assuming that the six countries found likely to be technically capable of producing UAS domestically are also able to effectively employ this technology, tertiary education data were sought after for the 30 remaining countries. Such data however are missing for Zambia, leaving the analysis to explore 29 countries in Africa. As shown in Appendix J and Figure 6.7, a tertiary education score was retrieved for each country.

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\(^{15}\) Wealthy nations were defined as having a GDP per capita at least one standard deviation above the sample mean.
Figure 6.7 Tertiary Education Level, by Country

Methodology

The 29 countries found less likely to have the capacity to manufacture UAS in-house (and for which data were available) were ranked by their tertiary education levels, as shown in Table 6.4.

Table 6.4 Countries Ranked by Their Ability to Effectively Use UAS Technology

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mauritius</td>
<td>30.5</td>
<td>16</td>
<td>Cabo Verde</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>Seychelles</td>
<td>29.7</td>
<td>17</td>
<td>Lesotho</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>Gambia</td>
<td>24.1</td>
<td>18</td>
<td>Niger</td>
<td>8.7</td>
</tr>
<tr>
<td>4</td>
<td>Cameroon</td>
<td>22.7</td>
<td>19</td>
<td>Togo</td>
<td>8.4</td>
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<td>Zambia</td>
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Figure 6.7 graphs the ordinal ranking of countries by their tertiary education scores. Higher tertiary education scores imply greater likelihood of successfully employing UAS technology, and poorer scores lower likelihood. The top five countries in tertiary education are by order Mauritius, Seychelles, Gambia, Cameroon, and Zimbabwe. The bottom five countries are Zambia, Swaziland, Malawi, Tanzania and Kenya.

6.6 Discussion & Conclusion

Notwithstanding the dual-use nature of UAS, which makes it spread throughout the world likely in the near future, literature suggests that countries’ capacity to adopt such innovative technologies depends on their technical capabilities and/or their ability to secure foreign assistance. Nevertheless, even if a country has the means and international backing to purchase UAS from foreign suppliers, a certain level of technical skill is also required to operate those systems effectively.

This chapter proposed a method to assess a country’s ability to develop and effectively employ agricultural UAS and applied it to 36 African countries for which data are available. In addition it reviewed the major international regimes that govern the UAS marketplace and which may hinder African’s countries’ ability to import this technology from abroad. The results were as follows:

- Six countries in Africa have a technical feasibility score that sets them apart from the other 30 countries studied in terms of the likelihood that they are technically capable of producing UAS technology. These countries are: Egypt, South Africa, Tunisia, Algeria, Morocco and Nigeria.
- All 36 countries analyzed have an equal chance of importing UAS from abroad except for Rwanda, which has a lower likelihood. Egypt is theoretically less likely to import UAS however, since Egypt is shown to be capable of producing UAS independently (and is known to already have UAS capabilities), its ability to import this technology is irrelevant in the context of this study. South Africa can more easily purchase UAS from foreign suppliers but the country is already an independent exporter of this technology.
- Tertiary education level data was collected for the 30 countries, which were not found capable of producing UAS domestically. These data were used as proxy to assess how well positioned these countries are for effectively employing this technology if purchased from abroad. The top 15 countries technically capable of operating UAS effectively: Mauritius, Seychelles, Gambia, Cameroon, Zimbabwe, Rwanda, Burkina Faso, Madagascar, Ghana, Ethiopia, Benin, Uganda, Burundi, Namibia and Botswana.

Open source data suggests that the following countries in Africa are in the process of acquiring UAS technology, either by developing it (e.g., Tunisia, South Africa) or by importing it (e.g., Egypt): Algeria, Angola, Botswana, Burundi, Egypt, Ethiopia, Cote d’Ivoire, Morocco, Nigeria, South Africa, Tunisia and Uganda. Libya is also reported to have UAS but it is not part of this study’s focus. The map in Figure 6.8 shows (the light areas) the countries in the world that have obtained, or are now in the process of developing, UAS capabilities.

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This chapter’s findings are correlated with these data for the most part. Egypt, South Africa, Tunisia, Algeria, Morocco, Nigeria have been found likely to be able to produce UAS domestically. Ethiopia is ranked 10th in its tertiary education score and Uganda 12th. Table 6.5 highlights the tertiary education scores of countries that already have or are working to obtain UAS capabilities.

### Table 6.5 Tertiary Education of Countries with UAS Technology

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<tr>
<th>Ranking</th>
<th>Country</th>
<th>Tertiary Education</th>
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<tr>
<td>10</td>
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The mean tertiary education level for the 30 countries is 13.83. Fifteen countries have scores are higher than the mean, and 15 below it. Except for Côte d’Ivoire and Angola, all other countries that currently possess or in the process of acquiring UAS technology have a tertiary education level above or at the mean level.

This chapter’s two sets of results (ranking of countries by the likelihood that they can develop UAS domestically; and ranking of countries by the likelihood that they can effectively operate this technology) cannot be merged because they are the products of distinct data and methodologies. Nevertheless, the rankings themselves can be combined to produce an overall ranking of the 36 countries’ innovation capacities and technical capabilities.
As shown in Table 6.6, the six countries found likely to be able to produce UAS in-house are first in this ranking by the order of their technical capacity scores. The other 30 countries are then listed by their tertiary education levels. Clearly, this ranking is not more than a symbolic representation of countries’ innovation capacity and technical capabilities. However, it is useful for gauging macro-level technical capacity among African countries, as well as for merging this component into the holistic analytical framework that seeks to depict inter-country variation in the likelihood of successfully adopting agricultural UAS technology.

<table>
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<td>2</td>
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<td>3</td>
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<td>Uganda</td>
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Chapter 7. Affordability & Economic Viability

7.1 Introduction

Chapter 6 assessed whether African countries are technically capable of developing UAS in-house, if they are well-positioned internationally to import this technology from abroad, and the extent to which their workforce is technically literate to employ UAS effectively. The objective of this chapter is to explore whether from an economic means perspective, African countries can afford to invest in or acquire UAS technology. While the analysis is performed at the national level, other levels of affordability (end-user and NGOs) are reviewed.

The rest of the chapter is organized as follows. Section 7.2 explains the concept of affordability at five theoretical levels. This section also explains how affordability is interpreted at the country level and reviews literature on the predictive role of national wealth in technology diffusion and use. Section 7.3 presents the data and methodology used to assess countries’ relative economic standing in terms of its ability to invest in UAS technology. Section 7.4 presents the findings from this analysis. Section 7.5 discusses these findings and concludes the chapter.

7.2 Affordability

Access to technology in developing countries is restricted across the board. One area highlighted in the literature is the limited access to health technologies, even basic ones. Another is ICT. Clearly, while not the only one, a major obstacle to access that has received substantial attention in the literature, is technology’s price. This focus on cost makes sense, especially when looking at access to technology for the poorest people in the world, who cannot afford technologies and whose poverty is exacerbated by the high prices they often confront, particularly for new technologies. Constrained economic resources also limit the ability of governments in poor countries to invest and purchase technologies for public benefit. Thus, lack of affordability is a problem in developing countries both at the national and at the household levels.

No more has the issue of technology affordability received more attention than during the late 1990s debate over access to antiretroviral drugs (ARVs) for treating HIV/AIDS in the developing world. This debate and efforts by the UN, activist groups such as the William J. Clinton Foundation, have led to 98 percent price reduction for triple-drug AIDS therapy between 1999 and 2003, from $12,000 a year to less than $200 a year.

Whether or not a technology is considered affordable depends on its price, cost of services and the available funds for purchasing it. In the case of UAS, their prices vary substantially depending on task, as shown by the two cases examined in chapters 3 and 4. Whereas the system for Quelea bird
control is not expected to cost over a few hundreds of dollars, the currently available UAS capable of performing aerial release as part of a SIT program is approximately $180,000.\textsuperscript{cdxxxvii}

Furthermore, the number of systems could vary by mission type. Again, while one VTOL UAS may be sufficient for a large geographical area, multiple ones are assumed to be necessary to scare of Queleas birds from several farms at the same time. The cost of services in the case of UAS, which are also not included in the assessment, are maintenance, storage, operation fees, batteries/chargers/generators and so forth. These costs will also vary depending on the context—for example, on whether the area of interest is connected to electrical grid, has storage facilities and so forth. In addition, a technology’s price can differ considerably across countries and between the public and private sectors within a country.\textsuperscript{cdxxxviii} This may be due to different corporate strategies, policy circumstances, tariffs, exchange rates, and negotiating conditions.\textsuperscript{cdxxxix}

As a result of this variation, it is not sensible to incorporate the actual price of UAS and the cost of services into affordability assessments. Clearly, it is an expensive technology which partly explains why most countries in the world do not currently possess it, as discussed in Chapter 6.

The analysis conducted in this chapter therefore is only concerned with assessing the economic means available for national African governments for investing or purchasing UAS technology. The focus on the economic viability at the national level stems from the overarching purpose of the analytical framework which is to assess inter-country variation in terms of the likelihood to successful adoption of agricultural UAS. However, whether a country may or may not afford UAS technology based on its national wealth captures only one dimension of the affordability puzzle. Research shows that government is not the only purchaser of technologies in developing countries. Rather, buyers of technologies in such countries can be crudely divided into five main groups, as listed in Figure 7.1.
These affordability levels are relevant for analyzing different implementation models. For example, a large scale program for Tsetse eradication is likely to be funded by one or more national governments or an international organizations (IGO), in similar to the Tsetse eradication campaign in Senegal, which was reviewed in Chapter 3 and was funded by the FAO. On the other hand, a sUAS for missions such as Quelea control (Chapter 4) may be appropriate for a community of farmers, an NGO, a national government or an IGO, depending on the scale of the program. Thus, even though this chapter only produces a quantitative metric for affordability at the national level, it is important to acknowledge the various levels of affordability and their relationship to different implementation designs. Depending on the context, other types of measures may be appropriate to assess the financial means of potential funders (one or more governments, NGOs, IGOs, farmer communities or individual farmers).

The next sub-sections discuss these different groups of potential funders of agricultural UAS and how they link to the concept of affordability. As shown, affordability at the national government scale—the focus of this chapter—comprises only one of these relevant levels.

### 7.2.1 Affordability at the End-User (Individual/Household) Level

Farmers are the largest source of investment in agriculture in low- and middle-income countries. In Sub-Saharan Africa, farmers invest approximately $19,038 million annually, accounting for 47 percent of all investments in agriculture. Farmers' investment in agriculture is centered on crop and animal husbandry activities and physical assets, including those used in the production process, livestock, machinery and
equipment, and others. This investment however is not in the area of technology. The level of mechanization in Sub-Saharan Africa remains very low with no sign for improvement, This situation can be illustrated by the extremely low numbers of tractors per 1,000 hectares of arable land—in 1980 there were 2 and by 2003 only 1.3. By comparison, in the Asia and Pacific region, in 1980 there were 7.8 tractors per 1,000 hectares and this had risen to 14.9 by 2003. While in 1960, Kenya, Uganda and Tanzania alone had more tractors in use than India, by 2005, India had 100 times more tractors in use than the total number in use in these three countries.

Therefore, the extent to which farmers invest in agriculture may not provide a direct indication of their ability to purchase technologies. Instead, it is useful to assess the ability of end-users in developing countries to afford technologies. This ability however depends on the type of the technology. For example, in the world’s poorest countries, most health technologies, including medicine, are purchased either by governments using their public budgets or by households using their own funds. As evident in the case of life-saving medicine, high prices prevent access to treatment for most patients in developing countries. Clearly, individuals and households in developing countries that cannot afford medical treatment and vaccinations are unlikely to be able to afford the relatively-costly agricultural UAS.

In the context of ICT, countries whose per capita income is higher have higher diffusion rate of these technologies. Research found that wealth explains approximately 50 percent of the disparities between ICT technology penetration rates in different regions worldwide. The large contribution of income to this gap may not be surprising considering the enormous disparities in income levels across regions of the world. While mobile phones have proven to be one of the most important technologies for low-income countries, this is not the case with the more costly computers. For example, in 2013, per capita Gross National Income (GNI; PPP adjusted) in the United States was $53,750. In contrast, the same year’s GNI PPP in Latin America and the Caribbean was $14,552, $13,761 in East Asia and the Pacific, and only $3,200 in Sub-Saharan Africa. The income gap is likely affecting ICT penetration by way of the cost relative to income. A personal computer costs on average $764. This figure represents about a quarter’s of a person’s average gross annual income in Sub-Saharan Africa.

The $3,200 average PPP GNI per capita for all Sub-Saharan countries is highly skewed as it includes for example Mauritius with PPP GNI of over $17,000 and Seychelles with GNI of $22,000 alongside some of the world’s poorest countries such as Malawi and Burundi with GNI of approximately $740. In addition, the GNI figure is based on the average income in all sectors. However, not all sectors are

16 GNI per capita based on purchasing power parity (PPP) is gross national income converted to international dollars using purchasing power parity rates. GNI is the sum of value added by all resident producers plus any product taxes (less subsidies) not included in the valuation of output plus net receipts of primary income (compensation of employees and property income) from abroad. Source: World Bank, International Comparison Program database.
associated with the same levels of poverty. Rather, more than 70 percent of the continent’s poor people live in rural areas and depend on agriculture for food and livelihood.\textsuperscript{cdi} Therefore, it is plausible to assume that the average income per capita among farmers in a certain country is lower than the national average.

The price of agricultural UAS would vary significantly depending on mission. However, even if considering only the least expensive models for tasks such as bird control, and assuming it would cost $150 per unit,\textsuperscript{cdi} as much as a low-cost commercially available hobby UAS, the technology would still be unaffordable for the vast majority of farmers in Africa. Ten of the 21 countries defined as in the regions of Eastern and Southern Africa have an average annual per capita income of less than $400.\textsuperscript{cdii} It is extremely unlikely that farmers—who may experience even higher degrees of poverty—would spend over a quarter of their annual income on bird-control technology.

Findings from the field study in Kenya corroborate this inference. As indicated in Chapter 4, only half of the farmers surveyed said that they could afford to spend money on Quelea control, and this expense was on average KES 5,050 per season with a standard deviation of 3,858.85 (around $50 with a standard deviation of some $40), much less than an inexpensive UAS. Further, Kenya’s PPP GNI ($2,670 in 2013) is higher than that of many African countries implying that farmers in poorer countries, e.g., Niger, Mozambique, Guinea, Togo, Ethiopia, Mali, Rwanda, and Madagascar,\textsuperscript{cdii} might find this technology even less affordable.

7.2.2 Affordability at the Farmer Group/Association Level

Most smallholder farmer operations in Africa occur within a network of relations at the community level.\textsuperscript{cdiv} In recent years, such community-based activity has been formalized with the establishment of official farmer groups, associations or organizations. A farmer association, organization, or group is a member-owned, private sector-oriented group, which is organized and managed by its members to meet the economic needs and aspirations of its members. Such groups appear in different forms of farmer unions, from village to national level, and they all share the objective of increasing benefits for the individual member farmer.\textsuperscript{cdv} In the context of this study, this term refers to village- or community-based groups engaged in agricultural production.

Agricultural research and advisory services are increasingly channeled through such farmer groups.\textsuperscript{cdvi} From governments’ or donors’ perspective, these groups create an efficient channel for engaging a particular target group in a development program. Further, working with these communities makes training and dissemination more efficient. From the farmer’s perspective, members of such associations can participate in decision-making processes and lobby for policy changes with a stronger voice. Moreover, it enables them to plan activities of common interest, and increase services for their community members including supply of agricultural inputs, credit financing, provision of transport, storage facilities, advisory and training services,\textsuperscript{cdvii} and potentially better economic means for technology purchase. Notwithstanding the small sample size of the field study in Kenya, findings support this trend of farmers working collectively as part of organized groups. Ninety eight percent of farmers
surveyed in Kenya said that they belong to a group. The average size of a farmer group reported was 26 members.

The scale of farmers’ investments in agriculture reported in the previous sub-section on end-user affordability level does not separate between investments made by individual farmers or groups. Considering recent trends, it is plausible to assume that a substantial part of farmers’ investments in agricultural capital stock is done in a community-based setting. Theoretically, 26 farmers earning $2,670 each annually can collectively purchase inexpensive UAS technology with collective funds of $69,420.

Indeed, this is clearly an overt simplification as farmers in groups are still poor, as the field study in Kenya found. Moreover, depending on mission, UAS may still be unaffordable even for farmer groups either because multiple systems may be necessary on a community-scale (as in the case of Quelea control), or because the UAS compatible for the task would be too costly (as in the mission envisioned in Tsetse eradication). Nevertheless, there is reason to believe that in general, if a technology is proven to be cost-effective, shown to improve agricultural yields and in turn increase profits, farmer groups may opt for purchasing it. Further, such groups are better positioned to purchase technologies than individual farmers, even if only because they can obtain better prices as a group.

A unique study on the feasibility of employing sUAS for community-based forest monitoring (CBFM) suggests that at the community level, imagery produced by sUAS are relatively inexpensive.\textsuperscript{cdlvii} While this study neither considered developing countries nor delivery/aerial application missions for UAS, it offers useful insight into the advantages and disadvantages of using UAS at the community level. This study found that the outlay required for purchasing, operating and maintaining a sUAS is rather low when compared with the cost of commissioning piloted aircraft missions or acquiring imagery from any of the high spatial-resolution satellites available (e.g., IKONOS, QuickBird, RapidEye) on a regular basis.\textsuperscript{cdlx}

Another advantage of the farmer-group level in adoption of new technologies is that in the event that a group decides to purchase a technology, trainers in the community can be selected from the farmers themselves, who then act as para-professionals in operation and maintenance of the technology. As demonstrated in a biotechnology project that was launched in Kenya in 2002 with the objective of benefitting small scale banana producers in the country, such trainers are the community’s reference ‘teachers.’ They understand the farmers better as they are part of the community.\textsuperscript{cdlx} In addition, even if a technology is purchased by an organization other than the group itself—be it government, an NGO or an IGO—such trainers can play a key role of linking farmers and the development agencies staff, making it easier to build the capacity of many farmers within a short time.\textsuperscript{cdliv}

\textbf{7.2.3 Affordability at the NGO Level}

Food and Agriculture NGOs are non-governmental organizations that address issues of nutrition, food security, and agricultural development in areas of the world that suffer from starvation and malnutrition. Such NGOs perform a variety of services, from large-scale distribution of food during crises
to long-term support of infrastructure in developing communities. Many food and agriculture NGOs work closely with small farmers in developing countries to improve crop yields and income levels, and collaborate with the United Nations' World Food Program (WFP) and other inter-governmental organizations (IGOs).

These NGOs vary significantly in size and budgets and hence making a meaningful assessment of NGO-level affordability is extremely challenging. However, a review of information on some major NGOs working in the field, coupled with insights gained by in-depth interviews with NGO personnel during the field study in Kenya, can shed light on different scales of NGO-level support.

Some of the major food and agriculture NGOs operating in Africa are as follows:\textsuperscript{cdlxii}

- One Acre Fund (OAF)—works to address food shortages in Kenya, Rwanda and Burundi by training small subsistence farmers on modern agriculture techniques and new environmentally friendly farming materials. Staff from OAF visited during the field study in Kenya said they are looking to learn more about how they can use UAS to support their farmers.\textsuperscript{cdlxii}
- FoodFirst Information and Action Network (FIAN)—works to protect humans’ right to food by exposing violations of this right.
- Mercy Corps—an international NGO that works to strengthen communities that have suffered from conflict, natural disasters or economic collapse, working among other issues in agricultural development and food security.\textsuperscript{cdlxiv}
- CARE—a humanitarian organization that works in 84 countries, helping communities adapt their agricultural practices to the changing climate.\textsuperscript{cdlxv}

There are many other NGOs working in areas of food security and agriculture in Africa but do so as part of a larger development agenda. For example, Christian Relief Services (CRS) is an organization that advances partnerships and in collaboration with grassroots charitable organizations in local communities worldwide.\textsuperscript{cdxvi} In meetings with CRS personnel in Nairobi, Kenya they have expressed interest in UAS technology for Quelea control. In other meetings with similar organizations across Kenya, NGO personnel said that one model of implementation may involve them as donors and providers of bird-control service in times of need. How affordable such a technology is will be determined on a case by case basis depending on a variety of factors including the magnitude of the problem, the agricultural task, the required UAS class, the quantity of UAS needed, the technology’s cost (net/gross), the degree to which it is effective in comparison to other alternatives, and the finances of the NGO.

### 7.2.4 Affordability at the IGO Level

An Intergovernmental organization is an organization that is composed primarily of sovereign states, or of other intergovernmental organizations, and that was established by treaty or other agreement.\textsuperscript{cdxvii} IGOs are often also referred to as international organizations and include for example the UN (in the area of agriculture—the FAO), the World Health Organization (WHO), the World Bank, the African Development Bank, WFP, and the European Union.
IGOs are deeply involved in development efforts in Africa, including in agriculture. Most efforts are concentrated on sectors such as agrarian reform, agricultural policy and administrative management, crop production, land and water resources; agricultural inputs, education, research, extension and training, plant and post-harvest protection and pest control; and others.\textsuperscript{cdxviii} According to data compiled from 70 countries, official development assistance in the area of agriculture amounts to some $1,027 million annually in Sub-Saharan Africa. This figure does not include development projects and programs that serve multiple purposes (for example, women empowerment through agriculture; or economic development through micro-loans to households, including farmers), as well as investments in R&D.\textsuperscript{cdxx}

The scale of IGO involvement in Africa in the area of agriculture is on the rise. Since the food price crisis of 2008, issues of food security have moved to the forefront of the international agenda. In 2009 the member nations of the G8 reaffirmed their commitment to improve food security and pledged $20 billion in assistance to developing countries over a period of three years.\textsuperscript{cdxx} This scale of commitment implies that IGOs have virtually unlimited means for technology purchases that could promote agriculture production and food security, depending on magnitude of problem and whether the potential solution is judged to be effective and feasible.

\textbf{7.2.5 Affordability at the National Government Level}

National governments invest in agriculture in a wide variety of area including: administration of agricultural affairs and service; conservation or expansion of arable land; agrarian reform; construction of flood control, irrigation and drainage systems including grants, loans or subsidies; support of extension services to farmers, pest control services; and more. In Sub-Saharan Africa, national governments invest $1,993 million in agriculture and additional $539 on agricultural R&D per annum, accounting for some 9 percent of total investment in agriculture (by farmers, private sector domestically and abroad, donors and so forth).\textsuperscript{cdxxi}

Government officials in Kenya interviewed for this study explained the extent to which they are involved in supporting smallholder farmer production of grains, from seed provision to training and post-harvest processing. Considering the magnitude of the Quelea challenge to small crop grain production in the country, these officials have expressed interest in supporting the purchase of UAS technology as means for bird control. Further, they raised the idea they would add UAS-based bird control to the services that they provide to farmers on demand. They will purchase the equipment, maintain it and have trained operators manage it.

While providing useful insight on the Kenyan Government principle willingness to support such an initiative, these observations do not offer true insight into government affordability in terms of investment in technology. And considering the low mechanization rates in agriculture across Africa, it is clear that most governmental investments in agriculture are not in new technologies. Therefore, it is useful to examine governmental investment in technology in other sectors.
Even though governments are not the only purchasers of technology in developing countries, they are the primary ones. A nation’s economic wealth, which is captured in the literature by GDP, GDP per capita or income per capita, has been considered a major determinant in the production and diffusion of a new technology. Many studies find a strong positive relationship between technology use and wealth across countries and within countries. Such studies have also shown that although not the only component, wealth differentials account for the single most important component of the global digital divide—defined as differences between individuals, households, companies, or regions related to the access to and use of ICT. Analyzing the main reasons explaining disparities between ICT technology penetration rates in different regions worldwide, studies found that differences in wealth explain approximately 50 percent of the gap in penetration rates.

In addition, ICTs require significant government investment for reliable and effective communication, and national and global communication networks are not possible without sufficient economic wealth. In other words, wealth generally predicts the likelihood of adoption and the extent of use of ICT because, among other reasons, it relates to infrastructure. Thus, when specialized infrastructures for adopting technologies are required, such technologies will be expected to be located in those areas with greater level of infrastructure. Wealth is also a determinant of ICT demand because it is usually associated with other complementary factors that have proven to be of critical importance in explaining the global digital divide, such as human capital (countries with more educated people will be prone to adopt and use innovations).

This rationale also applies to UAS which are not only a relatively expensive technology, but also one which necessitates substantial investment in infrastructure—ranging from basic electric power to communication systems, as well as fairly complex to operate. Thus, in the same vein, it is plausible to assume that national economic wealth has a predictive role in explaining the prospect that a nation will or will not be well-positioned to successfully adopt agricultural UAS.

7.3 Data & Methodology

Data

To assess the variation between the 36 countries of interest in this study in terms of their ability to afford UAS technology, this chapter utilizes the 2013 GDP per capita data, the latest year for which these data are available. GDP per capita is defined as the “gross domestic product divided by midyear population.” It is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars.

The use of GDP per capita for the assessment is consistent with previous research in the field. Data were retrieved from the World Bank’s national accounts data, and OECD National Accounts data files.
Methodology

The 36 African countries examined were ranked based on GDP per capita. Higher GDP implies greater likelihood of successfully employing UAS technology, and poorer scores lower likelihood, as shown in Table 7.1.

Table 7.1. 2013 GDP-Based Ranking of African Countries

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Country</th>
<th>GDP per Capita</th>
<th>Ranking</th>
<th>Country</th>
<th>GDP per Capita</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Seychelles</td>
<td>16185.90</td>
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<td>Lesotho</td>
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<tr>
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<td>Botswana</td>
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<td>Zimbabwe</td>
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<tr>
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<td>912.7</td>
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<td>5</td>
<td>Angola</td>
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<td>Benin</td>
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<tr>
<td>6</td>
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<td>Burkina Faso</td>
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<tr>
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<td>Algeria</td>
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<td>715.13</td>
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<td>8</td>
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<td>267.11</td>
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<td>Kenya</td>
<td>1245.51</td>
<td>36</td>
<td>Malawi</td>
<td>226.46</td>
</tr>
</tbody>
</table>

7.4 Findings: Country-level affordability

Table 7.1 presents the findings from the GDP-based ranking of the 36 African countries.

As shown, the five countries with the highest GDP per capita are in order of ranking: Seychelles, Mauritius, Botswana, South Africa and Angola. The lowest-ranking five countries (from bottom up) are Malawi, Burundi, Niger, Madagascar, and Gambia. The mean GDP per capita is $2,692 and the median is $1,185. For comparison, the world’s average GDP per capita in 2013 was $10,613. Thus, the average GDP per capita of the 36 countries studies accounts for about a quarter of global average, whereas the media is less than 12 percent of this figure. Of the 36 African countries, only Seychelles has a higher figure ($16,185.9), and Mauritius is lagging by some 10 percent. Even though making it to the top five,
Angola’s GDP is about half the world’s average. The GDP of countries ranked at the bottom such as, is only 2.3% of the global average.

7.6. Discussion & Conclusion

This chapter was concerned with assessing to what extent governments of the 36 African countries studied can afford UAS technology using their public budgets. As reported, in 2013 the mean GDP per capita of these countries was $2,692 and the median—$1,185. For comparison, the world’s average GDP per capita that year was $10,613. Thus, the average GDP per capita of the countries accounts for about a quarter of global average, whereas the median is less than 12 percent of this figure. Of the 36 African countries, only Seychelles has a higher figure than the global average ($16,185.9), and Mauritius is lagging by some 10 percent. The five countries with the highest GDP per capita are in order of ranking: Seychelles, Mauritius, Botswana, South Africa and Angola. The lowest-ranking five countries (from bottom up) are Malawi, Burundi, Niger, Madagascar, and Gambia. Even though making it to the top five, Angola’s GDP is about half the world’s average. The GDP of countries ranked at the bottom such as, is only 2.3% of the global average.

The low GDP per capita figures for most of the 36 countries studied implies that, based on national wealth only, these countries may not be well positioned to afford UAS technology simply by using their public budgets. This finding supports previous studies that found significant correlations between national wealth with technology adoption and use.\textsuperscript{cd\textsubscript{xxxvii}} It also helps explain the substantial role of external players—foreign governments, NGOs, IGOs, investment banks and private sector entities—in the effort to boost Africa’s development. In the area of agriculture, donors are making significantly increased commitments, and private-sector players and investment funds are investing substantially in this area.\textsuperscript{cd\textsubscript{xxxvi}}

Even though the focus of this chapter is the ability of national governments to purchase UAS technology, clearly governments are not the only purchasers of technologies in developing countries. Therefore, this chapter also reviewed four additional affordability levels: end-user (farmers); farmer groups; NGO’s and IGOs.

This division into affordability levels is not without limitations. First, the list of levels is not exhaustive. For instance, a foreign government can fund the adoption of a technology for a developing country, not as part of an intergovernmental organization. One prominent example is the U.S. Government agency U.S.AID, which in the context of agriculture coordinates efforts on part of multiple U.S. Government agencies for improving food security in the developing world.\textsuperscript{cd\textsubscript{xxxvi}} Clearly, the United States can afford UAS technology and supporting allies with this technology (recently the United States sent Kenya eight UAS units).\textsuperscript{cd\textsubscript{xxxviii}} Further, this division does not consider the role of foreign private sector. Previous research shows that it is often difficult to find commercial partners willing to develop or manufacture a technology for use in poor countries and thus the involvement, or absence, of the private sector can
Indeed shape the funding environment for investment in technologies. In Sub-Saharan Africa, foreign private investors account for only 0.08 percent of total investment in agriculture.\textsuperscript{cdxxxix}

Notwithstanding the relatively small scale of investment on the part of private investors, this sector will probably have a role in any implementation model should African countries adopt agricultural UAS. First, it is likely that the producers of these agricultural UAS will be foreign private companies. Second, and more generally, experts argue that sub-Saharan African agriculture alone requires additional investments of over $50 billion per annum, necessitating business models that can significantly increase the level of investment not only from the public sector and donors, but also from the private sector.\textsuperscript{cdxc}

Moreover, the formal NGO category applies to a few institutions that have more influence on the global development agenda than most national governments, the most prominent of which is the Bill & Melinda Gates Foundation. The trust endowment of this Foundation is $42.9 billion,\textsuperscript{cdxci} a figure larger than the GDP of the vast majority of African governments. However, in similar to wealthy national governments, such organizations were not considered here because obviously they can afford investing in UAS technology.

Finally, while the different affordability levels are treated as disparate, they have clear connections. Based on both literature reviewed for this chapter as well as insight gained during the field study in Kenya, it is safe to hypothesize that if agricultural UAS are to be adopted for a variety of missions in Africa, this adoption process will involve stakeholders that are aligned with different affordability levels. Just as in the Tsetse eradication effort in Senegal (studied in Chapter 3) is managed by the FAO, the U.S., France and the Senegalese government, any large scale program will require domestic and international funding and support. In addition, considering that manufacturers of agricultural UAS are likely to come from the foreign companies, there is reason to project a greater role for the private sector. Farmers will also be critical partners either as end-users of this technology or only as customers – depending on the implementation models. These theoretical models are context-dependend and hinge on multiple factors including type of agricultural mission, cost of the potential UAS solution, geographical range, countries involved (and their economic situation), etc.
Chapter 8. Governance & Institutional Feasibility

8.1 Introduction

Beyond a country’s innovation capacity, its workforce’ technical literacy and its national wealth, it is also important to investigate other dimensions that may influence the likelihood that it successfully adopt agricultural UAS. Evidence that adoption rates differ significantly between countries with similar economic and human capital situations suggest that other elements have a crucial role in technology adoption processes.\textsuperscript{cdxciii} The objective of this chapter is to investigate other variables that may influence African countries’ technological absorptive capacity, focusing on the role of governance and institutions in facilitating technology adoption.

Recently, research has shown that institutions, governance and political factors (as well as socio-cultural attributes and perceived values as will be discussed in Chapter 10) all affect such adoption decisions and the rates with which they are being made.\textsuperscript{cdxciii} Beyond the direct role that government has in this process as a supplier of technology, it also has a critical, albeit indirect, role. In particular, governments heavily influence the overall political and economic context, the quality of the business environment and the rules and regulations governing the conduct of business, all of which are crucial for technology diffusion processes.\textsuperscript{cdxciv} Previous studies demonstrate that differences in institutional support, business environment, governmental policies to boost R&D investments, and others explain technological gaps between countries.\textsuperscript{cdxcv} Furthermore, weak governance, instability and corruption can delay institutional and individual development and in turn hinder technological advancement and economic growth.\textsuperscript{cdxcvi}

Drawing on previous research that has established the role that prevailing macroeconomic, institutional and political conditions have on technology adoption, this chapter assesses inter-country variation in likelihood to successfully adopt agricultural UAS from an institutional and governance perspective. Even though it utilizes a reputable comprehensive assessment framework, the chapter does not aim to examine the whole range of governmental factors influencing UAS adoption. For instance, policies that determine gender equality (in the workplace or appointment to government) are also largely governmental. Nevertheless, because these do not have a direct visible link to agricultural UAS adoption they are not discussed. Moreover, the legal status of commercial UAS can either pose a barrier or serve as a driver in the technology’s adoption. However, data on the legality of UAS in most African countries is inaccessible, either as a result of a language barrier, or of restricted online access to legal documentation, or simply because there is legislation vacuum surrounding this issue as explained by Kenyan government officials.\textsuperscript{cdxcvii} Rather than attempting to examine the legal issue in each of the 36 countries of interest, it is reviewed in Chapter 2. It is plausible that African governments will adopt one of the legal regimes enacted by high-income countries with UAS capabilities such as the US, Japan, Australia and so forth. In Kenya for example, where the government is currently in the process of
drafting a law, government officials said they are using the US legal framework as a model for regulating civilian UAS flights.

Further, the difference in the legality of UAS may not be as pertinent to the analysis of inter-country variation in the likelihood that countries can successfully adopt the technology. The reason is that given a governmental decision to adopt UAS, the law can presumably be changed quickly to accommodate this decision. And a legal change can be assumed to be quicker than a broad institutional reform for example.

Thus, instead of analyzing the full set of governmental aspects that may or may not affect UAS adoption, this chapter uses secondary data and leverages existing research findings to examine how the most relevant institutional and governance factors influence the likelihood that African countries’ adopt this technology.

The remainder of this chapter is organized as follows. Section 8.2 defines and operationalizes the concepts of governance and institutions and reviews popular measurement tools. Section 8.3 introduces the data and methodology employed in this chapter. Section 8.4 reports and discusses findings from the analysis. Section 8.5 concludes this chapter.

8.2 Defining & Operationalizing the Concepts of Institutions, Governance

Good governance is considered an important goal not only in and of itself, but also as a means through which to impact a variety of other outcomes, particularly economic growth and development. In poorly governed countries, corruption, weak institutions and lack of accountability on the part of the government all hinder the development and implementation of pro-growth policies. As encapsulated by former UN Secretary-General Kofi Annan ‘good governance is perhaps the single most important factor in eradicating poverty and promoting development.’ While there is consensus about the importance of governance, the definition of this concept and the relationship between governance and institutions are more debatable.

First, governance is context-dependent. It can be used and assessed in relation to various settings, for instance at the institutional, corporation, communal, regional or national levels to include corporate governance, IT governance, NGO governance, national governance and so forth. In the context of this study, governance is referred to and assessed only at the national level.

In addition, the word “governance” has many definitions, most of which embody its relationship to institutions. For example, according the UN Development Program (UNDP), governance is ‘the exercise of economic, political and administrative authority to manage a country’s affairs at all levels,’ which ‘comprises mechanisms, processes and institutions through which citizens and groups articulate their interests, exercise their legal rights, meet their obligations and mediate their differences.’ The International Monetary Fund (IMF) defines governance as ‘the process by which public institutions conduct public affairs and manage public resources.’ Within the World Bank there are several
definitions for governance including ‘the exercise of political power to manage a nation’s affairs;’\textsuperscript{dvi} or ‘the manner in which public officials and institutions acquire and exercise the authority to shape public policy and provide public goods and services;’\textsuperscript{dvi} and the ‘traditions and institutions by which authority in a country is exercised.’\textsuperscript{dvi}

Despite differences in language, most definitions of governance include several common elements that are described rather generally and leave room for interpretation. These elements are as follows:\textsuperscript{dvi}

1. The act or manner of exercising authority (e.g., through a popular vote, consensus, physical force, orders by a supreme leaders etc.);
2. The power (or authority) (e.g., government agencies, rulers, religious leaders, judiciary, voting public);
3. The objective of managing the collective affairs of a community (country, society, or nation) (e.g., national security, infrastructure development, fiscal and monetary policies).
4. The principles, values, or norms that should be upheld in the process of governing;
5. The institutions that countries should have (for example, one such institution that well-governed countries should have in place according to the World Bank is free media).

As indicated by the various definitions mentioned above, structure plays an important in determining political behaviors, the overall patterns of governance, and the outcomes of political processes. Therefore, the quality of institutions is crucially important for developing, and sustaining, a well-functioning system of governance.\textsuperscript{dvii}

Measuring governance, and differentiating between countries with good versus poor governance, is also a topic of great debate the in literature.\textsuperscript{dviii} Numerous scholars and development practitioners have taken a stab at this effort and presently there are approximately 100 databases and indices designed to measure national-level governance or some component of it.\textsuperscript{dix} The vast majority of country-level governance index projects produce one or more composite indicators that combine multiple indicators to get single scores, grades, or ratings.

Some indices have gained more traction than others. Some of the most familiar ones are Country Policy and Institutional Assessment (CPIA), Transparency International’s Corruption Perceptions Index, Freedom House’s Freedom in the World, and of course the World Bank’s World Governance Indicators (WGI). The latter is the most commonly-used such index project. It combines elements from the academic and development policy worlds and provides six composite indicators, each designed to capture a different aspect of governance.\textsuperscript{dix} Similarly, the Ibrahim Index of African Governance (IIAG) also highlights links between research and Policy.

Clearly the WGI, IIAG and other governance and institutional indices are not without limitations. For one, as critics of such indices argue, it is overly simplistic to rank countries in one index.\textsuperscript{dxi} Moreover, an index at the national-level is not likely to capture the variation in governance at sub-national levels.\textsuperscript{dxii} Also, part of the challenge of measuring governance is the various data used. In addition to standard national statistics that is compiled in the census and by nationally-representative surveys, governance
indicators most often incorporate ratings by SMEs, elite surveys, coding of reports and imputed data.\textsuperscript{\textemdash}xiii Notwithstanding these limitations however, governance and institutional indicators present the most common methodology to assess countries along these dimensions in a simple, transparent and consistent manner.

8.3 Data & Methodology

This section introduces the indicators used and describes the methodology developed to gauge inter-country variation in terms of governance and institutional capacity. Findings based on these data and methodology will contribute toward the final holistic assessment of the likelihood that African countries adopt UAS technology.

\textit{Data}

To assess the variation between the 36 countries covered in the study in terms of governance and institutions, this chapter utilizes the latest IIAG from 2014. The IIAG was selected for the study not only because of its exclusive focus on Africa, but also for its reputation as one of the best-known measures of governance as well as its usefulness as ‘a well-established index that has become a reference point for governments and NGOs.’\textsuperscript{\textemdash}xiv

The IIAG was developed by the Mo Ibrahim Foundation, an NGO established in 2006 with ‘a focus on the critical importance of leadership and governance in Africa.’\textsuperscript{\textemdash}xv According to the Foundation, governance is defined as ‘the provision of the political, social and economic goods that a citizen has the right to expect from his or her state, and that a state has the responsibility to deliver to its citizens.’\textsuperscript{\textemdash}xvi The IIAG assesses governance progress for 52 African countries – all with the exception of Sudan and South Sudan, which were excluded following the secession of South Sudan in 2011.

IIAG’s assessment is conducted under four main conceptual categories, which in turn are made up of 14 sub-categories. Overall, the IIAG accounts for 130 variables, out of which 61 are clustered into 26 indicators, bringing the total number of indicators in the index to 95.\textsuperscript{\textemdash}xvii The four main categories and sub-categories are listed in Table 8.1. Figure 8.1 shows the overall 2014 IIAG used as basis for this chapter.
<table>
<thead>
<tr>
<th>Category</th>
<th>Sub Category</th>
</tr>
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<tbody>
<tr>
<td>Safety &amp; Rule of Law</td>
<td>Rule of law</td>
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<tr>
<td></td>
<td>Accountability</td>
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<tr>
<td></td>
<td>Personal Safety</td>
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<td></td>
<td>National Security</td>
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<td>Sustainable Economic Opportunity</td>
<td>Public Management</td>
</tr>
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<td></td>
<td>Business Environment</td>
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<td>Rural sector</td>
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<td>Participation</td>
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<tr>
<td></td>
<td>Rights</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
</tr>
</tbody>
</table>
Figure 8.1 Structure of 2014 IIAG
Methodology

To assess how African countries differ from one another in their governance and institutional capacity, this chapter does not employ the IIAG as is. Rather, it makes two important modifications to the index. First, it adjusts the Education sub-category to include only three of the seven original indicators comprising it. Second, it removes the category Participation & Human Rights altogether. The modifications are explained in detail below.

The nature of IIAG’s aggregation method makes such modifications quite simple. To aggregate the indicators, the IIAG uses linear, additive aggregation and nominally weight each sub-component equally within its dimension. According to the creators of the index, this method is favorable because it is consistent with weighing strategies used in constructing similar indices; it is simple; and transparent. Thus, in modifying the IIAG, the recalculations of scores required only revision of linear means.

Education Sub-Category Modification

The sub-category of Education consists of seven indicators:

1. Education Provision & Quality
2. Education System Quality
3. Ratio of Pupils to Teachers in Primary School
4. Primary School Completion
5. Progression to Secondary School
6. Tertiary Enrollment
7. Literacy

While all indicators are important outcomes of education policies, the last four account for the number of students achieving a certain level of education. Because tertiary enrollment was used in Chapter 6 as a proxy for the ability of country’s labor force ability to effectively employ UAS, it will not be accounted for here again. Assuming that students enrolling in tertiary education have had to complete primary and secondary schools as well as be literate, these indicators are also redundant with the previous effort on the human capital and are therefore not considered.

Removal of Participation & Human Rights Category

The Participation & Human Rights category consists of three sub-categories: participation, rights and gender. Participation accounts for indicators such as free and fair elections, political participation and political rights. Rights refer to freedom of expression, human rights, a country’s conformity with human rights conventions and others. Lastly, gender is composed of women participation in labor force, women in parliament, legislation on violence against women and more. While there are all important governance measures, that certainly fall within ‘the political, social and economic goods that a citizen has the right to expect from his or her state, and that a state has the responsibility to deliver to its citizens,’ there is no evidence that suggests that when it comes to military-civilian technologies, including UAS, this category is as relevant as the others.
First, research shows that both democracies as well as autocracies—markings opposite ends of governance spectrum in terms of free and fair elections, political participation, political rights, gender equality and other variables assessed under the “Participation,” “Rights,” and “Gender” sub-cATEGORIES—are as likely to pursue military UAS, although for entirely different reasons.

By definition, democracies are more accountable to their publics than autocracies. As such, they tend to fear the domestic political implications of casualties and are more likely to create capital-intensive militaries than labor-intensive ones. UAS is an example of a way through which democracies can substitute labor for capital, eliminating the risk for aircrew, and making it easier to conduct military operations. Indeed, democracies also allow for criticism against the use of technologies, as observed in the case of several NATO members that delayed the acquisition of armed UAS in response to public pressure at home. However, as a result of the proliferation of UAS globally, even countries like the UK, France and Italy, which once resisted the prospect of obtaining UAS capabilities, have eventually sought to purchase and/or develop this technology.

Autocratic leaders are freer than their democratic counterparts to pursue controversial technologies, including UAS. Moreover, they may find UAS useful for political repression of domestic opponents. China is a good example in this context. The People’s Republic, ranked in the bottom 10th percentile in voice & accountability according to WGI, deployed a surveillance UAS in August 2014 in response to a domestic round of riots and violence in Xinjiang.

Finally, a country’s desire to gain global legitimacy has been shown historically to serve as a strong motivation for acquiring modern military systems. “Status-seeking” countries wish to demonstrate their belonging to the international system, and do so often by developing, acquiring and even deploying military technologies not necessarily because of a need to improve military operations but rather because such technologies symbolize military power which is often equated with status. Applying the same logic to UAS, prestige-seeking countries may seek to acquire this technology because it is considered cutting-edge, is associated with Western power, and is discussed frequently as an important development in domestic and global affairs. Although prestige-seeking behavior can also characterize democratic countries, for instance in the cases of India and Chile—both countries see acquisition of UAS capabilities as a source of national pride—it is often associated with autocratic regimes.

North Korea is a case in point with its preference for maintaining its nuclear weapons even at the expense of growing global isolation. Similarly, Iran is considered a key prestige-seeking state for which acquiring nuclear power is a status symbol. In Iran, there is an element of prestige associated with joining the nuclear club and becoming the dominant power in the Persian Gulf. Tehran has also has made considerable investments in UAS recently and according to Iran’s news agency, the country successfully reverse-engineered an RQ-170 UAS that allegedly crashed in its territory in 2011.
As indicated below in the GAO map depicting the countries that acquired UAS as of 2011, the regime type—and hence its policies on participation, rights and gender—do not pose an obstacle to adoption of this technology. Along with liberal democracies such as the US, Canada, the UK, France, Germany, Israel, Japan and others, the map features non-democracies including Algeria, Jordan, Libya, Morocco, Syria and the United Arab Emirates. Since then, Saudi Arabia, a monarchy notoriously known for its human rights violations and lack of gender-equality, has also joined the list. In April 2014 Saudi started its first UAS fleet when it signed a contract with China for shipment of the latter’s Wing Loong, a UAV designed to mimic the US’ Predator.

**Figure 8.2 Map of Countries That Have Acquired UAS by 2011**

![Image of map](source.png)

**SOURCE: GAO, 2012.**

**IIAG Modification**

The modification of the IIAG reflects the adjustment of the Education sub-category to include only three of the original seven indicators, and the removal of the Participation & Human Rights category. Figure 8.3 illustrates the modified IIAG. In Lieu of listing the numerous remaining indicators still included in the index, the figure only shows the three remaining pillar categories (Safety & Rile of Law, Sustainable Economic Opportunity; and Human Development), and their sub-categories. All indicators comprising the sub-categories remain unchanged, as depicted in Figure 8.3, except for those of the Education sub-category, for which only the three indicators remaining are listed.
In computing the modified IIAG, all the data that the index contains were initially collected for the 36 countries of interest. The Education sub-category was recalculated as the arithmetic mean of the remaining three education indicators: Education Provision Quality, Educational System Quality and Ratio of Pupils to Teachers in Primary Schools, as shown in Appendix K. Subsequently, the Human Development category was recalculated as the arithmetic mean of its sub-categories: Welfare, Health and the adjusted Education domain.

The next step in the modification process was the removal of the Participation & Human Rights category, and recalculation of the overall governance score for each country as the arithmetic mean of the remaining categories (Safety & Rule of Law; Sustainable Economic Opportunity; and Human Development) as shown in Appendix L. Finally, countries were ranked by their modified IIAG scores, ranging from 0 to 100. Countries exhibiting higher scores are considered to have better governance and institutional capacity versus those ranked at the lower end of the scale.

8.4 Findings

The modified IIAG-based assessment produced an institutional ranking of the 36 African countries of interest. The top five countries are: Mauritius, Botswana, Seychelles, Cabo Verde, South Africa and Namibia. The lowest-ranking five countries from bottom up are Zimbabwe, Angola, Nigeria, Burundi,
Guinea and Côte d’Ivoire. As shown in Table 8.2, these rankings are quite consistent with the original IIAG-based ranking that also includes the Participation & Human Rights and the four education indicators that were removed excluded from the modified index. In terms of the top and lowest ranked countries, the difference between the modified-based ranking and the original one is only in the in which those countries are ranked. For example, whereas the original IIAG ranks Cabo Verde second, Botswana third, South Africa fourth, and Seychelles fifth, the modified index ranks Botswana second, Seychelles third, Cabo Verde fourth and South Africa fifth. Similarly, observing the bottom of the table, according to the original IIAG, Guinea is ranked 34th, Côte d’Ivoire 33rd, Burundi 32nd and Nigeria 31st. The modified index ranks Nigeria in the 34th place, Burundi in the 33rd, Guinea 32nd and Côte d’Ivoire 31st.
<table>
<thead>
<tr>
<th>Country</th>
<th>Modified Governance Score</th>
<th>Country</th>
<th>Governance Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mauritius</td>
<td>79.89</td>
<td>Mauritius</td>
<td>81.709</td>
</tr>
<tr>
<td>Botswana</td>
<td>73.99</td>
<td>Cabo Verde</td>
<td>76.595</td>
</tr>
<tr>
<td>Seychelles</td>
<td>71.31</td>
<td>Botswana</td>
<td>76.185</td>
</tr>
<tr>
<td>Cabo Verde</td>
<td>71.21</td>
<td>South Africa</td>
<td>73.290</td>
</tr>
<tr>
<td>South Africa</td>
<td>68.33</td>
<td>Seychelles</td>
<td>73.235</td>
</tr>
<tr>
<td>Namibia</td>
<td>66.11</td>
<td>Namibia</td>
<td>70.261</td>
</tr>
<tr>
<td>Ghana</td>
<td>64.30</td>
<td>Ghana</td>
<td>68.167</td>
</tr>
<tr>
<td>Morocco</td>
<td>63.34</td>
<td>Senegal</td>
<td>64.329</td>
</tr>
<tr>
<td>Tunisia</td>
<td>62.84</td>
<td>Lesotho</td>
<td>62.263</td>
</tr>
<tr>
<td>Senegal</td>
<td>58.89</td>
<td>Rwanda</td>
<td>60.357</td>
</tr>
<tr>
<td>Zambia</td>
<td>56.90</td>
<td>Zambia</td>
<td>59.436</td>
</tr>
<tr>
<td>Lesotho</td>
<td>56.76</td>
<td>Morocco</td>
<td>58.848</td>
</tr>
<tr>
<td>Swaziland</td>
<td>56.46</td>
<td>Tanzania</td>
<td>58.243</td>
</tr>
<tr>
<td>Gambia</td>
<td>55.63</td>
<td>Malawi</td>
<td>57.569</td>
</tr>
<tr>
<td>Kenya</td>
<td>54.45</td>
<td>Kenya</td>
<td>57.396</td>
</tr>
<tr>
<td>Malawi</td>
<td>54.15</td>
<td>Benin</td>
<td>56.671</td>
</tr>
<tr>
<td>Uganda</td>
<td>53.76</td>
<td>Uganda</td>
<td>56.128</td>
</tr>
<tr>
<td>Tanzania</td>
<td>53.72</td>
<td>Algeria</td>
<td>54.384</td>
</tr>
<tr>
<td>Algeria</td>
<td>53.60</td>
<td>Burkina Faso</td>
<td>53.278</td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>52.33</td>
<td>Mozambique</td>
<td>52.201</td>
</tr>
<tr>
<td>Benin</td>
<td>52.15</td>
<td>Gambia</td>
<td>51.550</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>50.53</td>
<td>Swaziland</td>
<td>51.508</td>
</tr>
<tr>
<td>Egypt</td>
<td>50.11</td>
<td>Egypt</td>
<td>51.105</td>
</tr>
<tr>
<td>Cameroon</td>
<td>49.56</td>
<td>Mali</td>
<td>49.470</td>
</tr>
<tr>
<td>Mali</td>
<td>49.05</td>
<td>Niger</td>
<td>49.436</td>
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<td>Niger</td>
<td>47.69</td>
<td>Ethiopia</td>
<td>48.494</td>
</tr>
<tr>
<td>Mozambique</td>
<td>47.30</td>
<td>Madagascar</td>
<td>48.175</td>
</tr>
<tr>
<td>Togo</td>
<td>46.92</td>
<td>Cameroon</td>
<td>47.646</td>
</tr>
<tr>
<td>Madagascar</td>
<td>44.97</td>
<td>Togo</td>
<td>46.448</td>
</tr>
<tr>
<td>Côte d'Ivoire</td>
<td>43.63</td>
<td>Nigeria</td>
<td>45.824</td>
</tr>
<tr>
<td>Guinea</td>
<td>42.60</td>
<td>Burundi</td>
<td>45.325</td>
</tr>
<tr>
<td>Burundi</td>
<td>42.30</td>
<td>Côte d'Ivoire</td>
<td>44.323</td>
</tr>
<tr>
<td>Nigeria</td>
<td>41.89</td>
<td>Guinea</td>
<td>43.285</td>
</tr>
<tr>
<td>Angola</td>
<td>40.91</td>
<td>Angola</td>
<td>40.927</td>
</tr>
</tbody>
</table>
8.5 Discussion & Conclusion

This chapter assessed the effect that governance and institutions may have on the likelihood that African countries adopt agricultural UAS. It drew on existing empirical and theoretical research and used the IIAG to rank countries along a governance and institutional spectrum. It provides useful insights into the governance and institutional differences between the 36 countries analyzed and adds an essential dimension to the overall framework assessing inter-country variation in terms of likelihood to successfully adopt agricultural UAS technology.

The original IIAG includes four pillar categories: Safety & Rule of Law; Sustainable Economic Opportunity; Human Development; and Participation & Human Rights. However, based on research that found that autocratic regimes—which would receive low participation, rates and gender scores, the sub-categories comprising the latter pillar—are as likely as democratic regimes to pursue UAS, the IIAG has been modified to exclude this category altogether. Further, the Education sub-category under the Human Development category originally consists of seven indicators. Yet, because four of them have been accounted for in one way or another in Chapter 6 in assessment of countries’ human capital capacity to employ UAS, this sub-category was altered to include only three of the seven variables.

Following the modification of the IIAG, the 36 African countries of interest were ranked based on their new governance scores. Higher scores represent greater likelihood that a country will be more institutionally suitable for adoption of a new technology, and a lower score indicates the opposite.

<table>
<thead>
<tr>
<th>Modified IIAG Ranking</th>
<th>Original IIAG Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ranking</strong></td>
<td><strong>Country</strong></td>
</tr>
<tr>
<td>36</td>
<td>Zimbabwe</td>
</tr>
</tbody>
</table>

Larger differences between the two rankings are noticeable for countries ranked closer to the governance & institutional mean (54.94). For example, Morocco is ranked 9th in the modified IIAG versus 13th in the original, and Swaziland is ranked 13th in the modified version compared with 23rd in the original. Such differences can be explained by the omission of the Participation & Human Rights category that lowers both countries overall governance score. Both are lower-middle income countries ruled by monarchies with low Participation & Human Rights scores: 37.5 out of 100 for Morocco and 31 for Swaziland. The fact that Morocco already has UAS capabilities confirms its higher position along the modified IIAG ranking and further validates the omission of the Participation & Human Rights category in the modified index for the purpose of this study.

This ranking represents countries’ likelihood of offering suitable governance and institutional capacity for adopting new technologies. The countries found most suitable in terms of governance and institutions level are Mauritius, Botswana, Seychelles, Cabo Verde and South Africa. On the other hand, the countries found least suitable on these grounds are Zimbabwe, Angola, Nigeria, Burundi and Guinea.
Even though the goal of the IIAG (as with other governance and institutional indices) is not explicitly to assess a country’s capacity to absorb new technologies, the index provides comprehensive and Africa-focused data. Further, it offers simple and transparent methodology to make such an assessment. The adjustment to the IIAG introduced above helped fit the analysis into the realm of military-civilian technologies, and UAS in particular.

This analysis has some limitations. First, while it captures many important indicators of governance and institutions, it does not account for all of them. For example, the legal dimension is pertinent to assessment of potential UAS use; however data limitations currently restrict in-depth comparative analysis of airspace laws and regulations between African countries. Further, the analysis relies on an index-based ranking and as noted above, a single index, even if comprehensive, cannot accurately capture governance nuances at the national and sub-national levels. Moreover, the IIAG uses linear, additive aggregation and nominally weighs each sub-component equally within its dimension. However, despite the usefulness of this approach, there is no evidence to suggest equal influence of each dimension, or of each sub-component within the different dimensions, on the degree of governance and institutional capacity. In addition, the data itself includes SMEs’ opinions, elite surveys and other sub-optimal data types which the accuracy of measuring governance this way. Finally, these findings are not UAS-specific.

To better understand how governance and institutional capacity may affect the likelihood that a country adopts new technologies, and UAS specifically, more in-depth analysis is needed. Such an analysis should for instance seek to capture the legal status of UAS. Moreover, it may utilize different data sources and not rely on a single aggregate index. For example, the analysis can offer deeper understanding of governance issues and how they may influence technology adoption by conducting in-depth interviews with governance and institutional experts, as well as country-specific specialists. Finally, future iterations of this effort should focus on UAS and look for correlations between specific governance and institutional variables—including but not limited to the indicators included in the IIAG—and data on UAS acquisition and development behavior.
Chapter 9. Cultural Feasibility

9.1 Introduction

National culture has long been considered an important element in technology acceptance.\textsuperscript{dxxxvi} Research has demonstrated that technology adoption decisions are highly subjective to the attitudes of the people of a country, and they may consequently be influenced by the country’s social and cultural characteristics. For example, cultural factors have been shown to influence mobile broadband service adoption among European countries along with political, economic and technological factors.\textsuperscript{dxxxvi} Other literature emphasizes the ways in which a country’s cultural base determines its entrepreneurial orientation.\textsuperscript{dxxxvi} Nevertheless, of all the factors influencing technology adoption, culture may be the most difficult to “isolate, define and measure.”\textsuperscript{dxxxix}

This chapter draws upon available empirical and non-empirical literature and suggests a methodology to assess from a cultural perspective inter-country variation in the likelihood that African countries successfully adopt technology in the near future. To complement the analysis, make it more UAS-specific, and understand how UAS are perceived in Africa, the chapter also includes an analysis of media in four countries: South Africa, Kenya, Nigeria and Egypt. As part of the media analysis, UAS-related news articles published in key newspapers in these four countries were analyzed by their tone of coverage (positive, negative, or neutral), and coded for themes.

The remainder of this chapter is organized as follows. Section 9.2 defines culture and explains how the concept is operationalized in research. Section 9.3 reviews the literature on the relationship between culture and technology adoption. Section 9.4 describes the data and methodology employed to assess inter-country cultural variation as it may apply to openess to new technologies. Section 9.5 presents the findings produce by this analysis. Section 9.6 features the media analysis including data, methods and findings. Section 9.7 concludes the chapter.

9.2 Defining and Operationalizing Culture

Culture has many definitions varying in their level of complexity and practicality. It has been defined for example as: the fabric of meaning through which people interpret events around them,\textsuperscript{dix} the manner in which a group of people solves problems and reconciles dilemmas,\textsuperscript{dxii} and the collective mental programming of a people that distinguishes them from others.\textsuperscript{dxii} Put simply, culture is characterized by shared values and norms and mutually reinforcing patterns of behavior.\textsuperscript{dxii} As an elusive and invisible concept, culture is hard to measure.

Perhaps the most popular cultural constructs are captured in Geert Hofstede’s Dimensions of National Culture.\textsuperscript{dxiv} What started as study within IBM in the years 1967-1973 “of how values in the workplace
are influenced by culture,\textsuperscript{186} has turned over four decades into a cross-national comparison of some 76 countries along four key cultural dimensions, and a fifth which was added later on. According to Hofstede and other scholars, these dimensions capture statistically the values that distinguish national cultures from one another and that influence whether nations adopt, or fail to adopt, new technologies. The dimensions as presented directly by the Hofstede Center are as follows\textsuperscript{186}:

- **Power Distance (PDI):** Power distance is the extent to which the less powerful members of organizations and institutions (like the family) accept and expect that power is distributed unequally. This represents inequality (more versus less), but defined from below, not from above. It suggests that a society’s level of inequality is endorsed by the followers as much as by the leaders.

- **Uncertainty Avoidance (UAI):** Uncertainty avoidance deals with a society’s tolerance for uncertainty and ambiguity. It indicates to what extent a culture programs its members to feel either uncomfortable or comfortable in unstructured situations. Unstructured situations are novel, unknown, surprising, and different from usual. Uncertainty avoiding cultures try to minimize the possibility of such situations by strict laws and rules, safety and security measures, and on the philosophical and religious level by a belief in absolute Truth. The opposite type, uncertainty accepting cultures, are more tolerant of opinions different from what they are used to; they try to have as few rules as possible, and on the philosophical and religious level they are relativist and allow many currents to flow side by side.

- **Individualism versus Collectivism (IDV):** Individualism on the one side versus its opposite, collectivism, is the degree to which individuals are integrated into groups. On the individualist side we find societies in which the ties between individuals are loose: everyone is expected to look after her/himself and her/his immediate family. On the collectivist side, we find societies in which people from birth onwards are integrated into strong, cohesive in-groups, often extended families (with uncles, aunts and grandparents) which continue protecting them in exchange for unquestioning loyalty. The word collectivism in this sense has no political meaning: it refers to the group, not to the state.

- **Masculinity versus Femininity (MAS):** Masculinity versus femininity refers to the distribution of emotional roles between the genders. The IBM studies revealed that (a) women’s values differ less among societies than men’s values; (b) men’s values from one country to another contain a dimension from very assertive and competitive and very different from women’s values on the one side, to modest and caring and similar to women’s values on the other. The assertive pole has been called masculine and the modest, caring pole feminine. The women in feminine countries have the same modest, caring values as the men; in the masculine countries they are more assertive and more competitive, but not as much as the men, so that these countries show a gap between men’s and women’s values.

- **Long Term Orientation (versus Short Term Normative Orientation) (LTO):** Long-term oriented societies foster pragmatic virtues oriented towards future rewards, in particular saving, persistence, and adapting to changing circumstances. Short-term oriented societies foster virtues related to the past and present such as national pride, respect for tradition, preservation of “face”, and fulfilling social obligations.
9.3 Culture and Technology Adoption

According to Hofstede, culture can be only used meaningfully by comparison and country culture relative scores on the Hofstede Dimensions have been proven to be quite stable over time. Further, these scores correlate with other data. Power distance, for example, is correlated with income inequality, and individualism is correlated with national wealth. In addition, masculinity is negatively related to the percentage of national income spent on social security. Furthermore, uncertainty avoidance is associated with the legal obligation in developed countries for citizens to carry identity cards, and pragmatism is connected to school mathematics results in international comparisons.

In the area of technology acceptance, uncertainty avoidance (UAI) and power distance (PDI) have been identified as the most influential cultural dimensions determining cross-cultural variation. UAI, in particular, is cited often as the most influential factor, and some empirical analysis identified PDI as important as well.

The relationship between PDI and technology adoption is not controversial—In general, low power distance countries show higher rates of adoption than high power distance countries. The influence of uncertainty avoidance however is more contentious. On one hand, Hofstede states that technological solutions appeal more to high UAI cultures because these are generally more predictable than human solutions. As a result, according to Hofstede, high UAI cultures are likely to adopt technology more easily.

At the same time, several subsequent studies that used Hofstede scores to examine the role of UAI in technology adoption have reached a completely opposite conclusion. They found that a fear of uncertainty results in resistance to adoption of technology in the first place. Uncertainty accepting societies are open to change and innovation, while uncertainty-avoiding societies are characterized by conservatism, law, and order. Therefore, people in uncertainty accepting societies are willing to try new products and technologies, whereas people in high UAI societies tend to be hesitant toward new products and information, thus they were slower in introducing new technologies.

Further, other studies that examined the timing of technology adoption found that high UAI cultures wait longer to adopt technologies. Research on wireless communication discovered that high UAI cultures delay investment and adoption of technology and rely more on observing the experiences of early adopters. Overall, these studies demonstrate that low UAI countries have higher adoption rates than higher UAI countries.

Interestingly, both the PDI and UAI dimensions influence technology adoption through the channel of trust. A popular technology consumer acceptance model suggests that trust influences the “intention to use” a new technology along with the perceived usefulness of the technology and the perceived ease of using it. In high PDI societies, superiors and subordinates consider each other as unequal and subordinates expect to be told what to do, while in low PDI societies, superiors and subordinates...
consider each other as equal and thus are interdependent. This is a necessary condition for trust because it indicates a willingness to be vulnerable under conditions of risk. Therefore, low PDI societies will exhibit more interpersonal trust, and consequently more trust toward new technologies than high PDI societies.\textsuperscript{dxx} Similarly, the lower degree of UAI will result in higher trust, and acceptance of a new technology.\textsuperscript{dxi}

Regarding other Hofstede dimensions, while some analyses found positive relationship between individualism (IDV) and ICT adoption, these have been inconclusive. Thus far there has been no strong support for relationships between the masculinity (MAS) and long term orientation (LTO) dimensions, and technology adoption.\textsuperscript{dxi}

### 9.4 Data & Methodology

This section draws on findings from the aforementioned literature review and assesses the likelihood that African countries successfully adopt UAS technology first based on the UAI dimension alone and subsequently on a combination of the PDI and UAI dimensions. The countries with lowest UAI and PDI/UAI scores are considered as more likely to culturally accept UAS technology in agriculture, while high UAI and high UAI/PDI countries are considered as less likely to culturally accept it.

**Data**

This chapter focuses again on the 36 countries introduced initially in Chapter 5, and which are listed in Table 9.1. The yellow highlighted cells indicate for which of these countries Hofstede has cultural scores along the PDI and UAI dimensions. Hofstede covers only 18 individual African countries, two of which are not the focus of this chapter (Libya and Sierra Leone). Thus, data are missing for 20 countries of interest. Table 9.1 shows for which country data are available (highlighted yellow cells) and for which data are missing.

<table>
<thead>
<tr>
<th>Table 9.1 Hofstede Coverage of African Countries of Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algeria Angola Benin Botswana Burkina Faso Burundi</td>
</tr>
<tr>
<td>Cabo Verde Cameroon Cote d’Ivoire Egypt Ethiopia Gambia</td>
</tr>
<tr>
<td>Ghana Guinea Kenya Lesotho Madagascar Malawi</td>
</tr>
<tr>
<td>Mali Mauritius Morocco Mozambique Namibia Niger</td>
</tr>
<tr>
<td>Nigeria Rwanda Senegal Seychelles South Africa Swaziland</td>
</tr>
<tr>
<td>Tanzania Togo Tunisia Uganda Zambia Zimbabwe</td>
</tr>
</tbody>
</table>

As Table 9.2 indicates, Hofstede also includes two aggregates, East and West Africa, which comprise the following countries, for which data are available:

- West Africa: Ghana, Nigeria, Sierra Leone.
<table>
<thead>
<tr>
<th>Country</th>
<th>PDI</th>
<th>UAI</th>
<th>IDV</th>
<th>MAS</th>
<th>LTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa East</td>
<td>64</td>
<td>52</td>
<td>27</td>
<td>41</td>
<td>32</td>
</tr>
<tr>
<td>Africa West</td>
<td>77</td>
<td>54</td>
<td>20</td>
<td>46</td>
<td>9</td>
</tr>
<tr>
<td>Angola</td>
<td>83</td>
<td>60</td>
<td>18</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>70</td>
<td>55</td>
<td>15</td>
<td>50</td>
<td>27</td>
</tr>
<tr>
<td>Cabo Verde</td>
<td>75</td>
<td>40</td>
<td>20</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Egypt</td>
<td>70</td>
<td>80</td>
<td>25</td>
<td>45</td>
<td>7</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>70</td>
<td>55</td>
<td>20</td>
<td>65</td>
<td>N/A</td>
</tr>
<tr>
<td>Ghana</td>
<td>80</td>
<td>65</td>
<td>15</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>Kenya</td>
<td>70</td>
<td>50</td>
<td>25</td>
<td>60</td>
<td>N/A</td>
</tr>
<tr>
<td>Malawi*</td>
<td>70</td>
<td>50</td>
<td>30</td>
<td>40</td>
<td>N/A</td>
</tr>
<tr>
<td>Morocco</td>
<td>70</td>
<td>68</td>
<td>46</td>
<td>53</td>
<td>14</td>
</tr>
<tr>
<td>Mozambique</td>
<td>85</td>
<td>44</td>
<td>15</td>
<td>38</td>
<td>11</td>
</tr>
<tr>
<td>Namibia</td>
<td>65</td>
<td>45</td>
<td>30</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>Nigeria</td>
<td>80</td>
<td>55</td>
<td>30</td>
<td>60</td>
<td>13</td>
</tr>
<tr>
<td>Senegal</td>
<td>70</td>
<td>55</td>
<td>25</td>
<td>45</td>
<td>25</td>
</tr>
<tr>
<td>South Africa</td>
<td>49</td>
<td>49</td>
<td>65</td>
<td>63</td>
<td>34</td>
</tr>
<tr>
<td>Tanzania</td>
<td>70</td>
<td>50</td>
<td>25</td>
<td>40</td>
<td>34</td>
</tr>
<tr>
<td>Zambia</td>
<td>60</td>
<td>50</td>
<td>35</td>
<td>40</td>
<td>30</td>
</tr>
</tbody>
</table>

SOURCE: Geert Hofstede’s Dimension data Matrix and Hofstede’s website.

To supplement missing data for the other African countries of interest, this study also looks at countries in aggregates but expands beyond the East and West Africa groupings used by Hofstede. First, it referred to the formal UN division of Africa into five regions: North, East, West, Middle and Southern-Africa. Many of the countries included in the UN’s five regions are beyond the scope of this study. Table 9.3 lists only the countries of interest by region in Africa.
Table 9.3 Countries of Interest, by Geographical Regions

<table>
<thead>
<tr>
<th>Region</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>Algeria, Egypt, Morocco, Tunisia</td>
</tr>
<tr>
<td>West</td>
<td>Benin, Burkina Faso, Cabo Verde, Cote d’Ivoire, Gambia, Ghana, Guinea, Mali, Niger, Nigeria, Senegal, Togo</td>
</tr>
<tr>
<td>Middle</td>
<td>Angola, Cameroon</td>
</tr>
<tr>
<td>East</td>
<td>Burundi, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Seychelles, Tanzania, Uganda, Zambia, Zimbabwe</td>
</tr>
<tr>
<td>Southern</td>
<td>Botswana, Lesotho, Namibia, South Africa, Swaziland</td>
</tr>
</tbody>
</table>

Source: UN Statistics Division

dxis

The UN’s division is not merely geographic but is also considered political. For the purpose of this assessment, this section assumes that geographical and political proximity also influences cultural attributes. Handling of missing data began by extrapolating from countries for which Hofstede scores are available to the other countries included within the formers’ geographic-political groups for which scores are missing. For example, the scores for Kenya (and Tanzania; these scores are identical) are assumed to be also appropriate for Uganda. The three countries are not only located in East Africa but also share a border, strong ties, close ethnic backgrounds, and cultural similarities.

With the exception of Middle Africa, each of the five regions is represented in Hofstede by more than one country, having different scores. The range of available scores posed a dilemma—how to choose the appropriate score for each country for which data are missing? For example, in North Africa both Egypt and Morocco have scores. However, which of these scores is most suitable for Algeria, Sudan and Tunisia?

To address this question, and to group countries together in a more nuanced manner than the UN’s crude division, eight subject matter experts were consulted. These experts have accumulated substantial knowledge of Africa either through living in the continent for a long period of time and/or through professional experiences specializing in Africa-related issues. Six of the experts are RAND researchers, and five of whom were born and raised in different countries in Africa (Nigeria, Ethiopia, Gabon, Togo and South Africa). Like the sixth SME, all have substantial work experience across Africa which has helped them gain knowledge on cultural similarities and differences between different countries. Two of the SMEs are external to RAND. One is an experienced development professional working across Africa. While originally from Kenya, this person has lied in multiple countries across the continent including South Africa, Ghana and others. The last expert was born and raised in Nigeria and has formal training in African studies.

Notwithstanding the astute judgment of the experts, lumping countries together has clear limitations, chief of which is that despite similarities, every country is different and unique in ways that this comparison fails to acknowledge. Nevertheless, given the shortage of cultural constructs and limited
data on Africa, it seemed appropriate for handling missing Hofstede scores for analyzing inter-country variations in the likelihood of adopting new technologies. While experts differed on some of the results, they generally agreed on the following country groupings:

**North Africa**
Includes four countries: Algeria, Egypt, Morocco, and Tunisia. Tunisia and Morocco are similar in terms of populations (primarily of Arabs and Bedouin). According to SMEs, Morocco’s PDI and UAI scores can be extrapolated to Tunisia. While Algeria is culturally and ethnically similar to Morocco and Tunisia (although south Algeria is also populated by the nomadic group Tuareg, like Libya), its political history is more alike Libya’s. Following a brutal war that ended years of French colonialization it is plausible to assume higher UAI values, and greater mistrust in anything Western, including technology. The score for Algeria therefore is the average between Morocco and Libya (although the latter is of no interest here, it has scores of PDI=80 and UAI=68).

<table>
<thead>
<tr>
<th>Score for</th>
<th>Extrapolated to</th>
<th>PDI</th>
<th>UAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morocco</td>
<td>Tunisia</td>
<td>70</td>
<td>68</td>
</tr>
<tr>
<td>Morocco/Libya</td>
<td>Algeria</td>
<td>75</td>
<td>74</td>
</tr>
</tbody>
</table>

**West Africa**
Includes 12 countries as indicated in Table 9.3. In general, most West Africans countries share many commonalities; nonetheless their colonialization histories influenced them significantly, an influence that has led to present-day variation in their cultures. Togo, Benin and Ghana are grouped culturally together, and thus the scores of Ghana will be applied for Togo and Benin as well. Cote d’Ivoire, Gambia, Guinea, and Senegal form a highly-French oriented group. Burkina Faso, Mali, and Niger are all quite similar as the old Mali Empire ruled all of Western Africa in the past and its influence is still present today in those countries. Both Nigeria and Cabo Verde have their own scores.

<table>
<thead>
<tr>
<th>Score for</th>
<th>Extrapolated to</th>
<th>PDI</th>
<th>UAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghana</td>
<td>Togo, Benin</td>
<td>80</td>
<td>65</td>
</tr>
<tr>
<td>Senegal</td>
<td>Cote d’Ivoire, Gambia, Guinea</td>
<td>70</td>
<td>55</td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>Mali, Niger</td>
<td>70</td>
<td>55</td>
</tr>
</tbody>
</table>

**Middle Africa**
The two Middle African countries of interest are Cameroon and Angola, for the latter data are available. SMEs noted that Cameroon is closest to Gabon and Congo as well as Eastern and Northern Nigeria. However, because there are no data for Gabon and Congo, and since the Middle African countries are considered similar, the score for Cameroon will be calculated as the mean of the scores for Nigeria and Angola.
East Africa

There are 13 East African countries of interest (Table 9.3). Kenya, Uganda and Tanzania are very similar as they are composed of a mix of Bantus, Nilotic and Semitic populations, and rely on agriculture and pastoralism. Hofstede also adds Ethiopia and Zambia to this East Africa aggregate. Burundi is most similar to Rwanda, for which Hofstede does not have a score, and shares some similarities with Uganda. Therefore the score of the East Africa aggregate will be extrapolated also to Burundi, and by extension, to Rwanda as well. Mozambique has its own score and so does Malawi.

Mauritius and Seychelles are very similar and have some similarity to Madagascar also. They are all Islands with ethnic mixes of Southeast Asian (Indian), East African, some Chinese and French ethnic groups. French is spoken in the three places as well as Creole and the major religions are Hinduism, Christianity, Islam and Buddhism. However, none of the three countries is covered by Hofstede’s dimensions. To overcome this problem, experts suggested that Cabo Verde, for which a score is available, is similar to Mauritius, Seychelles and Madagascar as they all share an island culture, consist of largely diverse populations and have strong trade relations with other countries. Finally, even though Zimbabwe is formally in East Africa its people are most similar to those of South Africa and therefore the latter’s scores will be applied.

<table>
<thead>
<tr>
<th>Score for</th>
<th>Extrapolated to</th>
<th>PDI</th>
<th>UAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Africa</td>
<td>Uganda, Burundi, Rwanda</td>
<td>64</td>
<td>52</td>
</tr>
<tr>
<td>Cabo Verde</td>
<td>Mauritius, Seychelles, Madagascar</td>
<td>75</td>
<td>40</td>
</tr>
<tr>
<td>South Africa</td>
<td>Zimbabwe</td>
<td>49</td>
<td>49</td>
</tr>
</tbody>
</table>

Southern Africa

There are five countries of interest in this region but only South Africa has a Hofstede score. Even though South Africa is an exception in the continent—it is far more industrialized than other countries—most of its population (traditional African ethnic groups alongside many ethnically European citizens) and history are similar to that of Botswana therefore the latter can be assumed to have similar PDI and UAI scores.

The peoples of both Lesotho and Swaziland are similar to the traditional Africans in South Africa, but without the Europeans. In addition, these two countries occupy very small territories and are monarchies. Despite the important economic influence of South Africa on the two kingdoms, they are significantly poorer and cannot be assumed to have an identical score to that of South Africa. Instead, because of Swaziland’s adjacency with Mozambique, its score and that of Lesotho will be calculated as the average scores of South Africa and East Africa which includes Mozambique.

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### Methodology

Following the methodology employed to complement Hofstede scores for the 21 countries for which data were missing, the analysis continued to produce UAI- and PDI-based rankings of the likelihood that African countries will adopt new technologies, including agricultural UAS. Initially, the 18 countries for which Hofstede has scores were ranked separately by their UAI and PDI scores, from lowest to highest. That is because:

1. Low PDI countries tend to have higher rates of technology adoption than high PDI;
2. Low UAI score implies greater cultural acceptance of technology and therefore higher likelihood of successful technology adoption.

As shown in Table 9.4, these two sets of rankings produced the following non-identical results, i.e., countries can have a low PDI but high UAI and vice versa. For the most part however, the results are somewhat similar except for in the notable cases of Cabo Verde and Mozambique (lowest UAI scores but ranked 13th and 18th in PDI, respectively), and to a certain extent Egypt and Morocco (#17, #18 in UAI scores but 12th and 11th in PDI, respectively). The second ranking column indicates a country’s rank in terms of its UAI and in parenthesis how it is compared to the PDI ranking. It is important to note that both PDI and UAI dimensions run on the same scale, from 0–100 with 50 as a midlevel. According to Hofstede, the rule of thumb is that if a score is under 50 the culture scores relatively low on that scale and if any score is over 50 the culture scores high on that scale.\textsuperscript{dlixiv}

<table>
<thead>
<tr>
<th>Score for</th>
<th>Extrapolated to</th>
<th>PDI</th>
<th>UAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Africa</td>
<td>Botswana</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td>South Africa, East Africa</td>
<td>Lesotho, Swaziland</td>
<td>56.5</td>
<td>50.5</td>
</tr>
</tbody>
</table>
Table 9.4 African Countries Ranked Separately by PDI, UAI Scores

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Country</th>
<th>PDI</th>
<th>Ranking</th>
<th>Country</th>
<th>UAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>South Africa</td>
<td>49</td>
<td>1 (13)</td>
<td>Cabo Verde</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>Zambia</td>
<td>60</td>
<td>2 (18)</td>
<td>Mozambique</td>
<td>44</td>
</tr>
<tr>
<td>3</td>
<td>Africa East</td>
<td>64</td>
<td>3 (4)</td>
<td>Namibia</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>Namibia</td>
<td>65</td>
<td>4 (1)</td>
<td>South Africa</td>
<td>49</td>
</tr>
<tr>
<td>5</td>
<td>Kenya</td>
<td>70</td>
<td>5 (2)</td>
<td>Zambia</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>Malawi*</td>
<td>70</td>
<td>6 (5)</td>
<td>Kenya</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>Tanzania</td>
<td>70</td>
<td>7 (6)</td>
<td>Malawi*</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>Burkina Faso</td>
<td>70</td>
<td>8 (7)</td>
<td>Tanzania</td>
<td>50</td>
</tr>
<tr>
<td>9</td>
<td>Ethiopia</td>
<td>70</td>
<td>9 (3)</td>
<td>Africa East</td>
<td>52</td>
</tr>
<tr>
<td>10</td>
<td>Senegal</td>
<td>70</td>
<td>10 (14)</td>
<td>Africa West</td>
<td>54</td>
</tr>
<tr>
<td>11</td>
<td>Morocco</td>
<td>70</td>
<td>11 (8)</td>
<td>Burkina Faso</td>
<td>55</td>
</tr>
<tr>
<td>12</td>
<td>Egypt</td>
<td>70</td>
<td>12 (9)</td>
<td>Ethiopia</td>
<td>55</td>
</tr>
<tr>
<td>13</td>
<td>Cabo Verde</td>
<td>75</td>
<td>13 (10)</td>
<td>Senegal</td>
<td>55</td>
</tr>
<tr>
<td>14</td>
<td>Africa West</td>
<td>77</td>
<td>14 (15)</td>
<td>Nigeria</td>
<td>55</td>
</tr>
<tr>
<td>15</td>
<td>Nigeria</td>
<td>80</td>
<td>15 (17)</td>
<td>Angola</td>
<td>60</td>
</tr>
<tr>
<td>16</td>
<td>Ghana</td>
<td>80</td>
<td>16 (16)</td>
<td>Ghana</td>
<td>65</td>
</tr>
<tr>
<td>17</td>
<td>Angola</td>
<td>83</td>
<td>17 (11)</td>
<td>Morocco</td>
<td>68</td>
</tr>
<tr>
<td>18</td>
<td>Mozambique</td>
<td>85</td>
<td>18 (12)</td>
<td>Egypt</td>
<td>80</td>
</tr>
</tbody>
</table>

Subsequently, the same countries were ranked by a composite indicator which combines UAI and PDI scores at equal weights. Again, the lower the score, the higher the likelihood that a country will be more open to adoption of a new technology. This ranking produces the following results, as shown in Table 9.5.
Table 9.5 African Countries Ranked by PDI&UAI Scores, Combined

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Country</th>
<th>PDI</th>
<th>UAI</th>
<th>PDI/UAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>South Africa</td>
<td>49</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td>2</td>
<td>Namibia</td>
<td>65</td>
<td>45</td>
<td>55</td>
</tr>
<tr>
<td>3</td>
<td>Zambia</td>
<td>60</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>4</td>
<td>Cabo Verde</td>
<td>75</td>
<td>40</td>
<td>57.5</td>
</tr>
<tr>
<td>5</td>
<td>Africa East</td>
<td>64</td>
<td>52</td>
<td>58</td>
</tr>
<tr>
<td>6</td>
<td>Kenya</td>
<td>70</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>Malawi</td>
<td>70</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>8</td>
<td>Tanzania</td>
<td>70</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>9</td>
<td>Burkina Faso</td>
<td>70</td>
<td>55</td>
<td>62.5</td>
</tr>
<tr>
<td>10</td>
<td>Ethiopia</td>
<td>70</td>
<td>55</td>
<td>62.5</td>
</tr>
<tr>
<td>11</td>
<td>Senegal</td>
<td>70</td>
<td>55</td>
<td>62.5</td>
</tr>
<tr>
<td>12</td>
<td>Mozambique</td>
<td>85</td>
<td>44</td>
<td>64.5</td>
</tr>
<tr>
<td>13</td>
<td>Africa West</td>
<td>77</td>
<td>54</td>
<td>65.5</td>
</tr>
<tr>
<td>14</td>
<td>Nigeria</td>
<td>80</td>
<td>55</td>
<td>67.5</td>
</tr>
<tr>
<td>15</td>
<td>Morocco</td>
<td>70</td>
<td>68</td>
<td>69</td>
</tr>
<tr>
<td>16</td>
<td>Angola</td>
<td>83</td>
<td>60</td>
<td>71.5</td>
</tr>
<tr>
<td>17</td>
<td>Ghana</td>
<td>80</td>
<td>65</td>
<td>72.5</td>
</tr>
<tr>
<td>18</td>
<td>Egypt</td>
<td>70</td>
<td>80</td>
<td>75</td>
</tr>
</tbody>
</table>

In the next phase, the rankings for the 18 original countries were extrapolated as indicated above to include the other countries of interest for which there are no available Hofstede score.

9.5 Findings

Table 9.6 ranks the full list of countries according to their combined PDI/UAI scores. Data for the countries highlighted in yellow are based on imputation.
Table 9.6 African Countries of Interest by PDI&UAI Scores, Combined

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Country</th>
<th>PDI</th>
<th>UAI</th>
<th>PDI/UAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>South Africa</td>
<td>49.0</td>
<td>49.0</td>
<td>49</td>
</tr>
<tr>
<td>2</td>
<td>Botswana</td>
<td>49.0</td>
<td>49.0</td>
<td>49</td>
</tr>
<tr>
<td>3</td>
<td>Zimbabwe</td>
<td>49.0</td>
<td>49.0</td>
<td>49</td>
</tr>
<tr>
<td>4</td>
<td>Lesotho</td>
<td>56.5</td>
<td>50.5</td>
<td>53.5</td>
</tr>
<tr>
<td>5</td>
<td>Swaziland</td>
<td>56.5</td>
<td>50.5</td>
<td>53.5</td>
</tr>
<tr>
<td>6</td>
<td>Namibia</td>
<td>65.0</td>
<td>45.0</td>
<td>55</td>
</tr>
<tr>
<td>7</td>
<td>Zambia</td>
<td>60.0</td>
<td>50.0</td>
<td>55</td>
</tr>
<tr>
<td>8</td>
<td>Cabo Verde</td>
<td>75.0</td>
<td>40.0</td>
<td>57.5</td>
</tr>
<tr>
<td>9</td>
<td>Madagascar</td>
<td>75.0</td>
<td>40.0</td>
<td>57.5</td>
</tr>
<tr>
<td>10</td>
<td>Mauritius</td>
<td>75.0</td>
<td>40.0</td>
<td>57.5</td>
</tr>
<tr>
<td>11</td>
<td>Seychelles</td>
<td>75.0</td>
<td>40.0</td>
<td>57.5</td>
</tr>
<tr>
<td>12</td>
<td>Burundi</td>
<td>64.0</td>
<td>52.0</td>
<td>58</td>
</tr>
<tr>
<td>13</td>
<td>Rwanda</td>
<td>64.0</td>
<td>52.0</td>
<td>58</td>
</tr>
<tr>
<td>14</td>
<td>Uganda</td>
<td>64.0</td>
<td>52.0</td>
<td>58</td>
</tr>
<tr>
<td>15</td>
<td>Kenya</td>
<td>70.0</td>
<td>50.0</td>
<td>60</td>
</tr>
<tr>
<td>16</td>
<td>Malawi</td>
<td>70.0</td>
<td>50.0</td>
<td>60</td>
</tr>
<tr>
<td>17</td>
<td>Tanzania</td>
<td>70.0</td>
<td>50.0</td>
<td>60</td>
</tr>
<tr>
<td>18</td>
<td>Burkina Faso</td>
<td>70.0</td>
<td>55.0</td>
<td>62.5</td>
</tr>
<tr>
<td>19</td>
<td>Cote d’Ivoire</td>
<td>70.0</td>
<td>55.0</td>
<td>62.5</td>
</tr>
<tr>
<td>20</td>
<td>Ethiopia</td>
<td>70.0</td>
<td>55.0</td>
<td>62.5</td>
</tr>
<tr>
<td>21</td>
<td>Gambia</td>
<td>70.0</td>
<td>55.0</td>
<td>62.5</td>
</tr>
<tr>
<td>22</td>
<td>Guinea</td>
<td>70.0</td>
<td>55.0</td>
<td>62.5</td>
</tr>
<tr>
<td>23</td>
<td>Mali</td>
<td>70.0</td>
<td>55.0</td>
<td>62.5</td>
</tr>
<tr>
<td>24</td>
<td>Niger</td>
<td>70.0</td>
<td>55.0</td>
<td>62.5</td>
</tr>
<tr>
<td>25</td>
<td>Senegal</td>
<td>70.0</td>
<td>55.0</td>
<td>62.5</td>
</tr>
<tr>
<td>26</td>
<td>Mozambique</td>
<td>85.0</td>
<td>44.0</td>
<td>64.5</td>
</tr>
<tr>
<td>27</td>
<td>Nigeria</td>
<td>80.0</td>
<td>55.0</td>
<td>67.5</td>
</tr>
<tr>
<td>28</td>
<td>Morocco</td>
<td>70.0</td>
<td>68.0</td>
<td>69</td>
</tr>
<tr>
<td>29</td>
<td>Tunisia</td>
<td>70.0</td>
<td>68.0</td>
<td>69</td>
</tr>
<tr>
<td>30</td>
<td>Cameroon</td>
<td>81.5</td>
<td>57.5</td>
<td>69.5</td>
</tr>
<tr>
<td>31</td>
<td>Angola</td>
<td>83.0</td>
<td>60.0</td>
<td>71.5</td>
</tr>
<tr>
<td>32</td>
<td>Benin</td>
<td>80.0</td>
<td>65.0</td>
<td>72.5</td>
</tr>
<tr>
<td>33</td>
<td>Ghana</td>
<td>80.0</td>
<td>65.0</td>
<td>72.5</td>
</tr>
<tr>
<td>34</td>
<td>Togo</td>
<td>80.0</td>
<td>65.0</td>
<td>72.5</td>
</tr>
<tr>
<td>35</td>
<td>Algeria</td>
<td>75.0</td>
<td>74.0</td>
<td>74.5</td>
</tr>
<tr>
<td>36</td>
<td>Egypt</td>
<td>70.0</td>
<td>80.0</td>
<td>75</td>
</tr>
</tbody>
</table>
This ranking represents countries’ likelihood of being culturally amenable to adopting new technologies, including UAS, from South Africa and Botswana on the top of the list to the Arab countries Sudan and Egypt at the bottom. Clearly, it has limitations.

First, it relies on extrapolation of data based on SMEs’ judgment. Moreover, it uses the mean of UAI and PDI for ranking although these dimensions may not share the extent to which they influence technology adoption. Future empirical research can identify the extent to which each dimension influences technology adoption and inform different weighing of these scores. Finally, these findings are not UAS-specific.

9.6 Media Analysis

To supplement the Hofstede dimensions-based analysis, and better understand how beliefs and attitudes pertaining specifically to UAS technology may affect the adoption of this technology, this section reports on the findings of a small scale analysis of media in four countries: South Africa, Kenya, Nigeria and Egypt.

9.6.1 Background

The Hofstede-based ranking was produced by assessing the likelihood that countries and peoples will or will not accept any new technology. It is general and not specific to UAS technology. The effort to characterize this likelihood is consistent with much of the work in the field of technology adoption and in line with the diffusion of innovation paradigm, which was mentioned in Chapter 5. However, one of the criticisms of this type of research is that it too much focuses on identifying ‘people’ differences with very little attention to analyzing the attributes of an innovation and its impact on the adoption decision and process. Understanding the attributes of an innovation is of particular importance, as individual beliefs of these attributes significantly predict most of the variance in future adoption and use.

The Technology Acceptance Model (TAM), which was also reviewed in Chapter 5, specifies a causal linkage between behaviors, attitudes, and beliefs. In this model, external variables influence technology acceptance behavior indirectly by affecting beliefs and attitudes. One such variable is the media. Literature has established that perceived risks of technologies are amplified by the reporting power of mass media.

Therefore, media analysis can shed light on how the discussion of an issue is framed, and in turn how it influences people’s beliefs and attitudes toward it. Most people have not been directly exposed to UAS and therefore mass media stories about it may play an important role in forming their impressions of this technology. Sensational coverage of an issue or an institution by the media can result in negative shifts of public attitudes toward it. On the other hand, media reporting can also highlight positive stories and increase public support. Further, whether UAS technology is considered a topic worthy of
front-page news, or ignored entirely, and how it is portrayed in different types of media outlets, can be
used to identify strategies for facilitating adoption of agricultural UAS.

Such sentiment analysis is popular for studying perceptions about public organizations, such as police, as
well as general issues including nuclear energy or genetically modified organisms (GMOs). Because of
the stigmatization of UAS—resulting primarily from its dual military-civilian nature—this methodology
seems suitable as a complement to the more general assessment of cultural openness to technology.

To assess how the media portrays UAS in different countries in Africa, the study carried out a systematic
media content analysis in four countries: Egypt, Kenya, Nigeria and South Africa. These countries
represent four distinct geographic and political regions in Africa, respectively: North, East, West and
Southern Africa. In addition, they are spaced across the cultural spectrum of likelihood to adopt new
technologies per the Hofstede Dimensions–based ranking. Unfortunately, the countries that represent
Middle Africa in the study, Angola and Cameroon, had no available online English newspapers to enable
such an analysis.

9.6.2 Data & Methodology

Initially, the database Lexis-Nexis was searched to retrieve all available English UAS-related reporting in
the press of all 36 African countries of interest. The keywords used were “UAS,” “UAV,” “drone,”
“unmanned aerial system,” and “unmanned aerial vehicle” and the period covered was from January 1,
2011 to February 6, 2015. The results were highly skewed between countries. For example, while for
South Africa hundreds of news items were found, for Burkina Faso there was none. The reasons for this
variation are numerous, the key of which are as follows:

- English is not an official (or key) language in many Africa countries. It is likely that news outlets
  in Algeria—an Arab and primarily Muslim country—the residents of which probably followed
closely the wars in Iraq and Afghanistan where military drones were used regularly—have
reported on UAS. However, because the official languages in the country are Arabic and French,
the search through Lexis-Nexis produced no results.
- Only a fraction of African newspaper titles are currently available online. Of an estimated
1,300 titles in circulation throughout Africa, only 484 titles with some form of active online
presence.\textsuperscript{dxxii}
- Internet penetration varies from region to region, and from country to country, and this
variation influences the number of active online titles in each place.
- Even though titles considered “significant” papers are reasonably well represented online, the
  technical sophistication and range of content presented on such sites varies widely.\textsuperscript{dxxiii}
- Of the 484 identified newspapers with online presence, 74 percent had search functionality.
  However, few had implemented advanced search capabilities beyond a simple site search. The
  presence and ease of searching previously published articles is, as a result, highly variable.\textsuperscript{dxxiv}

To ensure the lack of results is not only a consequence of Lexis-Nexis’ limitations, the study referred to
the BBC’s African country pages which provide general information on freedom of press and media
consumption, and lists the major media outlets in each country. In the cases where Lexis-Nexis failed to
capture a certain newspaper, I looked up the paper’s website and if one was found, searched it for the key terms. This targeted search of newspapers for each country added for the most part insignificant content to the initial Lexis-Nexis search, except for in the case of Egypt, and to a lesser degree Kenya and Nigeria. For example, while not retrieved by Lexis-Nexis, the search on Al-Ahram’s website, a major Egyptian newspaper controlled by the government, produced over 200 results. For most other countries, however, the main media outlets are not available in English and/or do not have a website, and/or search function.

Therefore, the study shifted its focus to only the four aforementioned countries—South Africa, Kenya, Nigeria, and Egypt—for which key newspapers are available in English and have online presence. In addition to their representation of four distinct geographic and political regions in the continent, the likelihood that these countries adopt new technologies is quite different from one another based on the Hofstede analysis. The top three newspapers, as identified by the BBC’s media African section and confirmed by the SMEs consulted on cultural similarities between African countries, were analyzed. In Egypt, Al-Ahram is known to be supported by the government (which also appoints the editor). According to the SMEs knowledgeable of South Africa, Kenya and Nigeria, none of the newspapers listed have known affiliations. Unfortunately, Middle Africa could not be analyzed because the two countries included in this region do not have available online English newspapers.

Table 9.7 lists the countries for which media analysis was conducted, their region, ranking along the Hofstede cultural feasibility scale, and newspapers covered.

<table>
<thead>
<tr>
<th>Country</th>
<th>Region</th>
<th>Ranking</th>
<th>Key Newspapers</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Africa</td>
<td>Southern</td>
<td>1</td>
<td>Business Day; Mail &amp; Guardian; The Sowetan</td>
</tr>
<tr>
<td>Kenya</td>
<td>East</td>
<td>15</td>
<td>Daily Nation; The East African; The Standard</td>
</tr>
<tr>
<td>Nigeria</td>
<td>West</td>
<td>27</td>
<td>Daily Trust; This Day; Vanguard</td>
</tr>
<tr>
<td>Egypt</td>
<td>North</td>
<td>36</td>
<td>Daily News; Egypt Independent; Al Ahram</td>
</tr>
</tbody>
</table>

Each newspaper, and each country, featured a different number of UAS-related articles. I coded the articles by their tone of coverage - positive, negative, or neutral. A second researcher from RAND with expertise in knowledge services assisted in the search for UAS-related reporting and coded the articles independently to ensure accuracy of results. Even if different outlets in each country featured a different number of relevant items, they were all lumped together to produce a country-level analysis. The breakdown of the items according to their classifications is shown in Table 9.8.
Table 9.8 Breakdown of News Items According to Country and Tone of Coverage

<table>
<thead>
<tr>
<th></th>
<th>South Africa</th>
<th>Kenya</th>
<th>Nigeria</th>
<th>Egypt</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>22%</td>
<td>26%</td>
<td>26%</td>
<td>2%</td>
<td>93</td>
<td>16%</td>
</tr>
<tr>
<td>Negative</td>
<td>49%</td>
<td>44%</td>
<td>52%</td>
<td>45%</td>
<td>278</td>
<td>47%</td>
</tr>
<tr>
<td>Neutral</td>
<td>29%</td>
<td>30%</td>
<td>22%</td>
<td>53%</td>
<td>215</td>
<td>37%</td>
</tr>
<tr>
<td>Total</td>
<td>104</td>
<td>80</td>
<td>168</td>
<td>234</td>
<td>586</td>
<td>100%</td>
</tr>
</tbody>
</table>

* Percentages are rounded.

9.6.3 Findings

Negative UAS-Related News Items Appeared More Frequently Than (Positive or Neutral Items

Even though most articles, in all categories, were succinct reports on recent events, almost half of them focused on the adverse aspects of UAS. As the analysis of themes describes in length below, such disapproving reports have mostly revolved around death of civilians, concerns regarding misuse of UAS by various players, proliferation of the technology and others. Nigeria featured the largest share of negative items (52 percent) followed by South Africa (49 per cent), Egypt (45 percent) and Kenya (44 percent). The differences between frequencies of negative coverage among countries is not remarkably significant and may be explained by the small sample size, the selection of only three key newspapers in each country, unavailable content in English, imperfect search engines or another technical reason.

Many of the UAS-Related News Items (37%) Were Neutral, with No Detectable Positive or Negative Tone

Such items were brief news updates on a UAS-related business transactions or disinterested reports on remote “drone strikes” that hurt militants. Egypt featured most neutral items (53 percent), followed by Kenya (30 percent) and South Africa (29 percent) and Nigeria (22 percent). The difference between Kenya and South Africa is negligible. The variation between Egypt and other countries in that regard may be explained by the frequency with which UAS is covered by the Egyptian press in comparison to the three other countries.

Only 16 Percent of UAS News Items Were Positive

Only 16 percent of UAS news items were positive, comprising approximately a quarter of items in the Kenyan and Nigerian press (26 percent in both), slightly less in South Africa (22 percent), and barely existing in Egypt (2 percent). Such positive stories reported on the technology’s ability to prevent animal poaching, save human lives, monitor infrastructure and deliver aide.
There is Merit to Treating This Technology as Controversial, or Stigmatized, in Africa as Well
Overall, the frequency of negative UAS coverage of UAS in the analyzed press, especially in comparison
to the paucity of positive items, implies that there is merit to treating this technology as controversial,
or stigmatized, in Africa as well.

Media Analysis Offers Partial Explanation into Inter-Country Differences
Most UAS-related news articles appeared in Egypt (40 percent), followed by Nigeria (29 percent).
Exposure was lower in South Africa (17 percent) and the lowest in Kenya (14 percent). This differential in
frequencies may be explained by the selection of only three major newspapers in each country, which
may not represent the full spectrum of media outlets, limited online content, imperfect search engines
and other reasons. Notwithstanding the limitations of this finding, the miniscule number of positive
articles on UAS in the Egyptian press supports the Hofstede-based ranking according to which Egypt is
least likely of the four countries to adopt new technologies in general, and a controversial one in
particular.

Fifty two percent of UAS items in the Nigerian press were negative, which supports its Hofstede-based
ranking as the country second least likely to adopt new technologies. On the other hand, it had an equal
share of positive items as South Africa, and slightly (but insignificantly) higher than Kenya’s which stands
in contrast to this ranking. Clearly, this finding is inconclusive and a more in-depth analysis is needed to
support or refute it.

The online newspapers selected for South Africa and Kenya had less UAS-reporting than in the Nigerian
and Egyptian papers, which may suggest less public exposure to a technology mostly portrayed as
negative, and hence more public acceptance. At the same time, both countries have similar shares of
positive reporting to that of Nigeria, and as high rates of negative reporting as Nigeria and Egypt, which
questions any attempt to make meaningful conclusions based on frequency counts. As in the case of
Nigeria, only more detailed media analysis can assess the sources of these seemingly contradicting
findings.

9.6.4 Analysis of Themes Sheds Light on Public Perceptions Regarding UAS
To understand the perceptions underlying the tone of coverage of UAS by the media, and in turn how
they inform the public, I identified key positive and negative themes. With the help of a second coder, I
sorted all news items according to their tone, read each item carefully, aggregated them by themes, and
examined their recurrence and variance between the four countries of interest.

9.6.4.1 Positive Themes Focused on UAS Technological Strengths
The review identified two positive themes, both praising UAS capabilities as they pertain to the two
areas in which this technology is employed—surveillance and delivery. Under each category, several
sub-themes are highlighted. News stories falling under these themes reported on how technological
developments allow channeling of UAS capabilities in positive directions.
Theme 1: Eyes in the Sky

This theme refers primarily to the capability of UAS to provide surveillance aide where it may have been lacking. Under this theme there are four sub-themes, categorized as types of non-traditional missions in which surveillance UAS can be employed: anti-poaching and wildlife conservation, protecting people as part of safety and security operations, helping in criminal investigations and improving news reporting.

Wildlife Conservation

This sub-theme refers primarily to the potential of UAS in anti-poaching campaigns and protection of wildlife. This theme was featured multiple times in newspapers from South Africa, Kenya and Nigeria and only once in an Egyptian paper. The frequency of this type of reporting has increased with most items having been published in 2014, which can be explained by recent developments of UAS and the repurposing of the technology to non-traditional uses. Examples of this sub-theme include:

“Drones Now Part of Anti-Poaching Arsenal” (Business Day (South Africa), February 8, 2013): dhxxvi

Surveillance drones are being deployed by the World Wildlife Fund (WWF) to combat rhino poaching. . . . The unmanned aerial vehicles . . . were being deployed in South Africa to protect not only rhinos, but all endangered wildlife. . . . The WWF’s three-year project also includes combining data from the unmanned aerial vehicles, using cheap cellphone technology to track animal movements and handheld devices carried by rangers. This would be in a bid to outsmart often heavily-armed poachers.

And:

“Anti-Whaling Activists’ Drone Tracks Japan Fleet” (This Day (Nigeria), December 25, 2011): dhxxvii

Anti-whaling activists intercepted Japan’s harpoon fleet far north of Antarctic waters on Sunday, they said, with the help of a military-style drone. Sea Shepherd Conservation Society spokesman, Paul Watson said that “[t]his is going to be a long hard pursuit. . . . But thanks to these drones, we now have an advantage we have never had before—eyes in the sky.

Improving Safety and Security of Human Lives

This sub-theme encompasses the use of surveillance UAS to actively protect human lives as part of security and safety operations. Stories in this realm include for instance the use of surveillance UAS in UN peacekeeping operations, in search of kidnapped persons (i.e., in the case of the kidnapping of some 300 school girls in Nigeria in April 2014), dhxxviii or rescuing of migrants in peril at sea. For instance:

“Italy Rescues 300 Migrants, Sends Navy Ships, Drones on Patrols” (Al-Ahram (Egypt), October 15, 2013): dhxxix

Italy’s navy rescued about 300 migrants in the waters between Sicily and Libya on Tuesday as the government deployed ships, helicopters and unmanned
drones to help avert further shipwrecks that have already drowned hundreds this month.

And:

“UN Peacekeepers Launch Surveillance Drones in Congo” (Business Day (South Africa), December 4, 2013).dlxxx

United Nations (UN) forces in the Democratic Republic of the Congo launched unmanned aircraft on Tuesday to monitor the volatile border with Rwanda and Uganda, the first time UN peacekeepers have deployed such surveillance drones. The aircraft will be used to look out for threats from a host of local and foreign armed groups. . . . “The drones . . . will allow us to have reliable information about the movement of populations in the areas where there are armed groups,” UN undersecretary-general for peacekeeping operations Herve Ladsous said.

Law Enforcement

Stories in this sub-theme are concerned primarily with the employment of surveillance UAS in law enforcement operations, either in direct fight against criminal activity or in border patrol or maintenance of safe cities. Examples include:

“Obiano Raises the Bar on Crime Fighting, Deploys Drones to Track Kidnappers” (This Day (Nigeria), July 29, 2014).dlxooi

The intense crackdown on criminals in Anambra State entered a new phase at the weekend when Governor Willie Obiano announced his readiness to deploy drones . . . to smoke out criminals in the state from their hiding places for immediate arrest and prosecution. The governor who spoke at the final test-running of the drones . . . before their deployment to trouble-spots across the state also declared the resolve of his administration to sustain the campaign against kidnappers, armed robbers and other types of organized crime in the state.

And:

“City of Cape Town Plans to Acquire Drones” (Mail & Guardian (South Africa), September 12, 2014).dlxooii

The City of Cape Town’s Mayco Member for Safety and Security JP Smith, said in a meeting with the police last week that the City aims to test drones within the next two months. In an interview . . . Smith . . . said that different departments within the City—metro police, disaster management, fire and rescue and engineering departments—have had to spend money on hiring helicopters for aerial surveillance. The acquisition of a drone . . . could be more cost-effective. Drones would be used to monitor land occupations, crime, scrap yards suspected of harboring stolen copper, shack fires and disasters.
Improving News Reporting

Surveillance drones are also being touted as potentially helpful to improving news reporting through the provision of more accurate and timelier information, as demonstrated in the following item:

“CNN Launches Research for Drones in Journalism” (*Daily Nation* (Kenya), June 24, 2014):

CNN has said it was launching a research project with the Georgia Institute of Technology on how drones could be used for newsgathering by media organizations. . . . “Our hope is that by working cooperatively to share knowledge, we can accelerate the process for CNN and other media organizations to safely integrate this new technology into their coverage plans,” said David Vigilante, CNN senior vice president, in a statement. Georgia tech researcher Mike Heiges said drones “have a number of applications that benefit society, such as search and rescue, disaster response and agricultural mapping and crop assessment,” and added that “we’re excited to be engaging with CNN to study the newsgathering applications” for drones.

Theme 2: Facilitating Delivery

This theme encapsulates UAS delivery capabilities primarily of medical supplies and consumer goods, either in rural or in urban areas, as depicted in:

“When the Drones Go Dancing” (*Mail & Guardian* (South Africa), August 22, 2014):

[a graduate of Pretoria University] Mark Müller describes Amazon’s drone delivery concept as an offshoot of an older idea, that of the Internet of Packages. It is presently spearheaded by a company called Matternet, which describes its approach as the “lowest cost, lowest energy, lowest ecological footprint, most easy to set up, most easy to reconfigure” transportation system it has yet created. “They want to deliver goods like medicines in Africa using multicopters, to deliver to hard-to-reach places,” says Müller. “The idea is that the vehicles easy to maintain and manage, and if you have a network of these vehicles and deliver packages from node to node, it works a little like how the internet delivers packets of data to computers via nodes spread across the internet. They want to deliver real packages in the same way.

And:

“Amazon to Deliver Your Online Orders Using Drones” (*Daily Nation* (Kenya), December 2, 2013):

The world’s largest retailer Amazon is testing unmanned drones to deliver goods to customers. The Amazon chief executive Jeff Bezos told CBS television that drones could be used to deliver packages weighing up to 2.3kg to the customer within 30 minutes. . . . Amazon just like any other online store has been working to deliver customer goods as fast as possible compared to the brick and mortar ones. . . . The mini drones could cover a radius of about 16 kilometers making them useful especially in urban settings.
9.6.4.2 Negative Themes
There were also three main negative themes: adverse consequences of using UAS, misuse of the technology and fears concerning its proliferation.

**Theme 1: Adverse Consequences**
This theme is concerned primarily with the killing of civilians by military armed UAS, referred in the press as “drones.” Articles in this theme were common in newspapers of all four countries and comprised the majority of negative items altogether. Examples of articles expressing this sentiment include:

“Yemen Wedding Convoy Strike Highlights Civilian Drone War Toll” *(Daily Nation (Kenya), December 14, 2013)).*

A drone strike on a wedding convoy in Yemen killed 17 people, mostly civilians, medical and security sources said Friday, adding grist to mounting criticism of the US drone war. “Some” of the dead in Thursday's strike near the central town of Rada were suspected members of Al-Qaeda, but the rest were all civilians with no connection to the jihadist network, a security official said.

And:

“Obama Victory Infuriates Pakistani Drone Victims” *(Egypt Independent (Egypt), November 2012)).*

Drone strikes are highly unpopular among many Pakistanis, who consider them a violation of sovereignty that cause unacceptable civilian casualties. Whenever he has a chance, Obama will bite Muslims like a snake. Look at how many people he has killed with drone attacks,” said Haji Abdul Jabar, whose 23-year-old son was killed in such a bombing. Analysts say anger over the unmanned aircraft may have helped the Taliban gain recruits, complicating efforts to stabilize the unruly border region between Pakistan and Afghanistan.

**Theme 2: Misuse of UAS**
This theme refers to the deliberate misuse of UAS technology primarily by non-state violent actors. In addition, there are fears that such misuses are carried out by poachers who themselves use UAS to track down animals. Finally, it captures the perceived deliberate misuse of the technology by the United States as the news piece from the Nigerian paper Daily Trust demonstrates.

“West Africa: At the Mercy of Drones and Turbans” *(Daily Trust (Nigeria), March 1, 2013)).*

The rate at which the security situation is deteriorating across the Sahel and West African sub regions is quite frightening. . . . For instance, the recent establishment of the deadly drones base in the neighboring Republic of Niger by the United States of America, to supposedly track down and kill terrorists operating in the region . . . represent an alarming escalation of the level of involvement of foreign intelligence agencies and other state and non-state actors, who increasingly engage in covert activities in the region to exploit the crisis in their struggle against one another.
And:

“Unregulated Drones Pose a Security Threat, Says Peters” (Business Day (South Africa), August 13, 2014):\textsuperscript{dxc}

Unmanned flying machines, or drones, could be used by terrorists to plant bombs and, when unregulated, pose a serious risk to the security of South Africans and the country, Transport Minister Dipuo Peters said. . . She also said safety risks associated with drones included collisions with aircraft, falling out of the sky and injuring or killing people on the ground, and being a threat to wildlife if they crash in the veld and start fires. “The security risks, among others, include an intentional act to kill or harm an individual by deliberately flying into him or her. An intentional act to attach a bomb to an RPA with the intention to harm persons or property,” Ms. Peters said. . . There was also the risk of drones being used for the smuggling or running of drugs, guns or other contraband into prisons or other areas.

Theme 3: Fear of Proliferation

A fear of UAS proliferation, primarily in autocratic states, but also among terrorist groups and criminal organizations, was noted by papers of all four countries. Egypt was mostly concerned with Iran’s acquiring UAS capabilities whereas in South Africa a sentiment was raised against export of the technology to Saudi Arabia.\textsuperscript{dxci} In other cases however newspapers reported on smuggling of UAS into prisons and the risks of criminals obtaining such capabilities. For instance:

“Iran Says Extracts Data from U.S. Spy Drone” (This Day (Nigeria), December 5, 2012):\textsuperscript{dxcii}

Iran has obtained data from a U.S. intelligence drone that shows it was spying on the country’s military sites and oil terminals, Iranian media reported its armed forces as saying on Wednesday. . . In December 2011, Iran said it had captured a U.S. RQ-170 reconnaissance drone in eastern Iran which was reported lost by U.S. forces in neighboring Afghanistan. Iranian commanders have since announced they have extracted valuable technology from the aircraft and were in the process of reverse-engineering it for their own defense industry.

And:

“Drones Thrill Martha Stewart . . . and US Prison Convicts” (Daily Nation (Kenya), August 1, 2014):\textsuperscript{dxciii}

In South Carolina . . . the state Department of Corrections asked the public for help Thursday in identifying a second suspect in a failed attempt to airlift contraband into a prison filled with hardened criminals. Mobiles phones, marijuana and tobacco made up the illicit payload of the small drone that crashed before it could get inside of the Lee Correctional Institution, which houses about 1,000 convicts. It was discovered in bushes in April, and one person has already been taken in into custody. But the case only went public
this week as law enforcement released surveillance images of a potential second suspect. “This is definitely a new and interesting way” to smuggle contraband into a prison, Department of Corrections spokeswoman Stephanie Givens told AFP by telephone.

9.6.5 Discussion

Different mixes of themes appeared in each country’s papers. The Egyptian press was distinctively more concerned than South Africa, Kenya and Nigeria about armed UAS strikes in the Middle East. This is not surprising considering that Egypt is a leading Arab country that is closer in culture and affinity to the Middle East rather than Africa. In addition, the fear that UAS technology would fall into Iran’s hands was only raised in Egyptian newspapers, reflecting a historical Sunni-Shia divide represented by a rift between Iran and the Arab Sunni world. Hence, not only the frequency of UAS-related news items in Egyptian press, but also the country’s Arab and Muslim identity, may make it more prone to be cautious of UAS.

The positive sub-theme concerning the use of UAS to prevent animal poaching featured in South Africa and Kenya, two countries that struggle to conserve their wildlife. This issue was barely mentioned in Nigeria papers and not at all in the Egyptian one.

Furthermore, only newspapers in Sub-Saharan Africa (i.e., South Africa, Kenya and Nigeria) discussed how UAS can be used to save people either if used in UN peace keeping operations or in search and rescue missions. The most popular in the context of the latter was the employment of surveillance UAS to look for the hundreds of Nigerian school girls who were kidnapped in April 2014. Not only an issue of national security for Nigeria, but the kidnapping has also turned into a pan-African story. The difference in the frequencies with which it was reported in the Sub Saharan papers and Egypt reinforces the point about the dissimilarity between Egypt and the other three countries.

Interestingly, the unique attributes of UAS, which are reflected in the positive themes, are raised as concerns in the negative themes if the technology falls into the wrong hands. This dual sentiment may simply manifest natural resistance toward a new innovation that can temper over time. However, it may also reflect a genuine concern as to who owns and operates this technology and suggest an important role for regulation, monitoring and enforcement.

Clearly there are some limitations to this media analysis. First, the selected newspapers (three in each country) encompass only a fraction of the media to which publics in South Africa, Kenya, Nigeria and Egypt are exposed. Second, only English items were analyzed and while English is the formal language of South Africa, and an official language in Kenya and in Nigeria, it is not an official language in Egypt and is not read by all. Third, it is impossible to know if all UAS-related content is indeed available in English and online. Despite these limitations however, the analysis does yield useful insights on how the media—and presumably the corresponding publics—perceive UAS in those countries.

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9.7 Conclusion

This chapter assessed the effect that national cultures may have on the likelihood that African countries adopt agricultural UAS. It drew on existing empirical and theoretical research and used Hofstede’s Cultural Dimensions UAI and PDI. These dimensions data were available for only 16 of the 36 countries of interest, thus official country groupings and SMEs were consulted to extrapolate scores for the 20 countries for which data were missing. Countries were then ranked according to their combined UAI-PDI scores, with lower scores representing a higher likelihood that a country will be more open to adoption of a new technology, and a higher score indicating the opposite.

This analysis has important limitations. First, the decision to examine the role that culture may have in technology adoption in the context of this study is constrained to begin with given the elusiveness of this concept and the lack of capacity to run in-depth field studies in each of the countries of interest. Second, even though the SMEs consulted before countries were grouped together are tremendously knowledgeable about Africa, each country is different from one another, having sub-cultures and tribes within them, which make any lumping attempt suboptimal. This in turn affects the accuracy of the ranking. Moreover, although Hofstede offers the most comprehensive framework of national cultures values it is problematic. One criticism of Hofstede for instance is concerned with its disregard for other dimensions along which culture can be analyzed. In addition, Hofstede has been accused in collecting data in a skewed manner interviewing primarily sales and engineering personnel with few women and minorities. Finally, using equal weights of UAI and PDI to produce the ranking may not reflect the true extent to which these dimensions influence technology adoption. Further research can inform more accurate ranking efforts in the future.

Still, this analysis provides insight into the cultural differences between the 36 countries analyzed and adds a useful dimension to the overall framework assessing inter-country variation in terms of likelihood to adopt agricultural UAS technology.

To supplement the Hofstede-based assessment and better understand the manifestation of cultural inclinations along the UAI and PDI dimensions in public sentiment, a small scale media analysis was conducted. This analysis provided lens into public perceptions vis-à-vis UAS technology. The analysis sought to gain insight not only to distinct geographical regions in Africa but also to represent countries spaced along the cultural spectrum of likelihood to adopt new technologies per the Hofstede Dimensions–based analysis. Due to data limitations, language barriers and technical challenges, the analysis focused only on four countries that met these criteria and for which UAS-related news items were available online and in English:

- South Africa (region: Southern Africa; ranking by Hofstede: 1st)
- Kenya (region: East Africa; ranking by Hofstede: 15)
- Nigeria (region: West Africa; ranking by Hofstede: 27)
- and Egypt (region: North Africa; ranking by Hofstede: 36)
The first step in the media analysis was a frequency count of UAS-related news for each country by their tone of coverage (i.e., positive, negative and neutral). Subsequently, articles were coded for themes. The small scale media analysis found that the negative UAS-related items appeared most frequently (47 percent), followed by neutral (37 percent), and lastly positive (16 percent). This finding suggests that UAS is indeed a controversial technology. The frequency of negative items was pretty similar for all four countries. However, a larger variation was found in the distribution of neutral and positive items. For example, for Egypt—a country found to be least likely of the four countries to be culturally open to adopt new technologies in general, and a controversial one in particular—only two percent of the news stories were positive.

As for South Africa, Kenya, Nigeria, that are ranked 1st, 15th and 27th based on the Hofstede UAI and PDI dimensions, the media analysis produced primarily inconclusive findings. The reason for this inclusiveness may be small sample size, the selection of only three key newspapers in each country, unavailable content in English, imperfect search engines or another technical reason.

The main limitations of the media analysis are discussed above. In addition, this analysis’ focus on English readers only in four countries may not represent public perceptions vis-à-vis UAS across the continent of Africa. Nevertheless, The frequency with which UAS news are being reported, and the tone with which they are covered, are thus speculated to be important factors in determining public perceptions regarding UAS. Furthermore, they offer explanations to puzzles that emerged from the cultural Hofstede-based ranking. For instance, Egypt already has UAS capabilities. In addition, it was ranked first by technical feasibility and 10th in affordability, as shown in chapters 8 and 7, respectively. Yet, it was ranked last in cultural feasibility (and the 24th in institutional capacity. The media analysis offers an insight into some of the reasons that may underline cultural resentment toward technology, and a controversial one such as UAS in particular.

Finally, by depicting public perception of UAS, the analysis can inform public policy makers that seek to overcome public resistance to adoption of UAS. As described above, the themes captured by the African newspapers are reminiscent of UAS-related news reporting in the United States and Europe and thus it is likely that some versions of these themes may also be apparent in other African countries if UAS are discussed. For example, the media in the four countries examined portrays UAs as dangerous—as captured in the themes, it leads to undesired consequences; it can be misused; and its proliferation is risky. Thus, policy-makers interested in favorable public opinion to UAS adoption may wish to disassociate agricultural UAS from their military equivalents, the “drones.”

To better understand how the media’s portrayal of UAS in the four countries discussed as well as other African countries, a more in-depth media analysis is needed. Such an analysis should seek to address the major limitations of this chapter and pursue not only online English newspapers but also: newspapers in other languages (e.g., Arabic in Egypt; French in Tunisia, Algeria and Morocco), print newspapers not available online, radio and television clips, and even social media content. In addition, to ensure media analysis reflects public sentiment, such analysis should be backed by country-specific surveys and if needed, focus groups.
The cultural feasibility assessment is the fifth element in the analytical framework that was introduced in Chapter 5. Notwithstanding the contribution of the media analysis, it covered only four of the 36 countries of interest in this study. Thus, the results of the Hofstede-based ranking will populate the cultural piece of the framework. These results, combined with findings from chapters 6–8, will help depict inter-country variation in the likelihood that African countries successfully adopt agricultural UAS technology.
Chapter 10. Results from the Analytical Framework: Feasibility Likelihood Evaluation

10.1 Introduction

Chapters 5–9 sought to assess to what extent non-technological factors may influence the likelihood that African countries successfully adopt agricultural UAS in the near future. To do so, these chapters developed and populated a novel analytical framework that helped depict inter-country variations in the likelihood of adopting this technology. The objective of this chapter is to combine the findings from these chapters and offer a holistic ranking of African countries by their likelihood to successfully adopt agricultural UAS technology.

The rest of this chapter is organized as follows. Section 10.2 provides an overview of the analytical framework and its components. Section 10.3 combines the findings from chapters 6–9 and presents a holistic ranking of African countries by their likelihood to successfully adopt agricultural UAS technology. Section 10.4 discusses these findings and concludes the chapter.

10.2 Overview of Analytical Framework

Drawing on previous efforts to empirically study and theoretically formulate technological adoption processes, this framework incorporates both micro- and macro-level elements. As explained in Chapter 5, the framework is comprised of four key pillars that have been identified as critical for successful adoption of technologies in general and dual-use technologies such as UAS in particular. These pillars are as follows:

1. **Innovation capacity & technical literacy of the workforce:** whether a country’s human capital endowment is technically equipped to obtain and use UAS technology for agriculture. Literature on military technological innovation diffusion in general, and on UAS in particular, suggests that a country’s adoption of advanced technologies depends on its technical capabilities. A novel method was developed to assess UAS-specific technical capacity. This method involved scaling the GII by the publication frequencies in disciplines relevant for UAS production. In addition, this analysis utilized data on tertiary education. In addition, this dimension also addressed non-technical factors that determine a country’s ability to import UAS technology by examining regimes that govern the UAS international marketplace.

2. **Affordability & Economic viability:** the degree to which a country can afford—to be wealthy enough—to invest in UAS technology. A nation’s economic wealth has been considered a major determinant in the production and diffusion of a new technology. National wealth is measured in this study by GDP per capita.

3. **Governance and institutional feasibility:** the quality of a country’s governance and institutions in support of investment, technology growth, and human progress. Previous research has shown that institutions, governance and political factors all affect technology adoption decisions and
the rates with which they are being made\textsuperscript{dxcvii}. To measure the quality of governance and institutions, the study proposed a modification to the IIAG.

4. \textit{Cultural feasibility}: the degree to which a national culture may enable or hinder the adoption of new technology. Potential cultural acceptance of UAS was assessed using two dimensions of Hofstede’s Dimensions of National Culture, as well as media analysis of newspapers in South Africa, Kenya, Nigeria and Egypt.

Thirty six countries were assessed along each of the aforementioned five dimensions:

- Algeria
- Angola
- Benin
- Botswana
- Burkina Faso
- Burundi
- Cabo Verde
- Cameroon
- Cote d’Ivoire
- Egypt
- Ethiopia
- Gambia
- Ghana
- Guinea
- Kenya
- Lesotho
- Madagascar
- Malawi
- Mali
- Mauritius
- Morocco
- Mozambique
- Namibia
- Niger
- Nigeria
- Rwanda
- Senegal
- Seychelles
- South Africa
- Swaziland
- Tanzania
- Togo
- Tunisia
- Uganda
- Zambia
- Zimbabwe
They were ranked based on the likelihood that they successfully adopt agricultural UAS along the specific dimension examined. Subsequently, the four rankings dimension-specific rankings are weighed equally and combined, producing a final likelihood-based ranking depicting the variation between countries’ holistic capacity to effectively adopt this technology.

Notwithstanding the usefulness and comprehensiveness of this framework, it is important to acknowledge its limitations. First, it does not cover all the elements that may influence a country’s chances of successfully adopting UAS, e.g., the legal status of using this technology commercially. However, as mentioned earlier, due to missing data, the legality aspect could not be addressed. Moreover, even though the four dimensions (technical, institutional, cultural, and economic feasibility) are assessed separately, they may not be entirely independent from one another. Yet, for analytical simplicity it is assumed that the five dimensions are standalone. Finally, equally weighing the five dimensions in the final ranking may not be accurate. The influence of certain dimensions may be more prominent than others under different circumstances. Nevertheless, this approach not only offers a general way to assess inter-country variation in ways that are not context-specific, but it is also consistent with strategies used in similar frameworks; it is simple; and transparent.

10.3 Findings

Table 10.1 presents a summary of the rankings along each dimension as well as the combined ranking. The six countries ranked as most likely to successfully adopt this technology are South Africa, Mauritius, Seychelles, Botswana, Namibia and Cabo Verde. The six countries least likely to be able to do so are: Togo, Guinea, Niger, Mozambique, Mali and Malawi.
An examination of the rankings shows that these countries are not necessarily included in the top or bottom six along each and every specific dimension. In fact, only South Africa and Botswana are amongst the six countries most likely to successfully adopt UAS along each of the four dimensions. Namibia is amongst the top six countries in three dimensions: affordability, institutional and cultural feasibility. However, it is ranked 20th in technical feasibility. Mauritius and Seychelles are ranked in the top six in affordability and institutional feasibility. They are ranked 7th and 8th in technical feasibility, and 10th and 11th in cultural feasibility respectively.

None of the six countries least likely successfully adopt agricultural UAS is ranked in the bottom six per along each and every dimension. Togo is included in the bottom six in cultural feasibility. It is ranked 29th in institutional feasibility, 28th in affordability and 25th in technical feasibility. Mozambique is not

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amongst the bottom six in any dimension. However, it is close to the bottom along all four dimensions—29th in affordability, 28th in institutional feasibility and 26th in technical and cultural feasibility.

The maps in Figure 10.1 offer a clearer visual representation of the inter-country variation in the likelihood to successfully adopt agricultural UAS. Using stoplight colors, this visual depiction offers a convenient way to assess the extent to which a country is likely to adopt this technology in the near future. The maps were produced using ArcGIS based on the underlying data utilized in developing and populating the analytical framework.
Figure 10.1 Maps Depicting Inter-Country Variations in Likelihood to Successfully Adopt UAS; All 36 Countries
10.4 Discussion

The output of the framework developed in this study offers a convenient way to assess inter-country variation in the likelihood that African nations can successfully adopt agricultural UAS technology. In particular, the maps provide a simple visual illustration of this variation. Using stoplight colors, this visual depiction allows for first-order feasibility-based comparison of countries. Moreover, it points out along which dimension a country may be stronger or weaker. This indication in turn informs the development of concrete policy recommendations. For example, Namibia, ranked 5th in the combined ranking seems overall well-positioned to adopt agricultural UAS in an effective manner. Yet this broad picture masks Namibia’s possible challenge in terms of the technical literacy of its workforce. Thus, policy-makers seeking to adopt UAS in Namibia may wish to focus their efforts on technical training of potential operators.

On the other hand, an analysis along only one dimension can be misleading as well. For example, Ghana is ranked 33rd in cultural feasibility, and is not ranked very high (although in the top half) on affordability (14th) and technical feasibility (15th). However, Ghana is ranked 13th by the combined ranking. Apparently, Ghana has relatively strong institutions which can create conducive environment for technology adoption. Thus, if policy makers are interested in adopting UAS in Ghana, they may want to prioritize its efforts on improving cultural acceptance of this technology.

Further, the modular nature of the framework allows for different levels of analyses, ranging from dimension-specific, through partial, to holistic. In addition, this framework can be used to assess the variation in likelihood of successfully adopting agricultural UAS only between countries that neither have nor are in the process of acquiring UAS capabilities. The underlying assumption for focusing solely on these countries could be that possessing the technology is sufficient for effective adoption.

Thirteen of the 36 countries assessed fall under this category: Algeria, Angola, Botswana, Burundi, Egypt, Ethiopia, Cote d'Ivoire, Kenya, Morocco, Nigeria, South Africa, Tunisia and Uganda. The remaining 23 countries were ranked along both the individual dimensions as well as the combined feasibility ordering, as shown in Table 10.2. The five countries that are now most likely to adopt UAS successfully are Mauritius, Seychelles, Namibia, Cabo Verde and Lesotho. Mauritius, Seychelles and Namibia were among the five countries most likely to successfully adopt UAS in the original ranking. Cabo Verde was ranked 9th and Lesotho 11th. The two countries were pushed up the ranking because many of the countries that occupied high rankings already have, or are in the process of obtaining, UAS capabilities.
Table 10.2 Combined Feasibility Ranking for Countries That Currently Do Not Have UAS Capabilities

<table>
<thead>
<tr>
<th>Affordability</th>
<th>Technical Feasibility</th>
<th>Institutional Feasibility</th>
<th>Cultural Feasibility</th>
<th>Combined Feasibility</th>
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<td>Ranking</td>
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<td>1</td>
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<td>Namibia</td>
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<td>4</td>
<td>Cabo Verde</td>
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<td>Swaziland</td>
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The five countries least likely to do so are Togo, Guinea, Mozambique, Niger and Malawi. All of these countries were also included in the bottom six of the 36 original countries analyzed. Overall, there is not much difference between the lists in the low-ranking countries.

Here again, visual representation of this inter-country variation provides a convenient first-order analysis of the likelihood that African countries without UAS capabilities can effectively adopt agricultural UAS technology as illustrated in Figure 10.2.
Figure 10.2 Maps Depicting Inter-Country Variations in Likelihood to Successfully Adopt UAS; Only Countries Without UAS Capabilities
The modularity of the framework is especially useful in examining the countries that currently do not have UAS capabilities. For instance, a potential donor may wish to fund an agricultural UAS program in a certain country as part of a broader development agenda. Under such circumstances, whether the national government of that country can afford to purchase this technology is irrelevant. At the same time, the donor should ensure that this country has proper institutions that can support the implementation of the program, labor force that can employ UAS effectively and a public that is likely to accept such a technology.

A comparison of the map that depicts inter-country variation between all nations versus the one that compares between the 23 countries without UAS capabilities is also informative, as shown in Figure 10.3. For example, in 2014 Kenya launched a $103 million program to deploy surveillance in all of its 52 national parks and reserves in a bid to monitor and stop the poaching of elephants and rhinoceroses. The program was funded partly by Kenya but mostly by United States, Netherlands, France and Canada, and the technology itself is U.S.-made. This recent development supposedly turned Kenya into a country with UAS capabilities that presumably can effectively adopt UAS successfully. However, recently, the U.S. State Department is examining the use of manned aircraft instead because apparently the Kenyan Wildlife Service (KWS) is facing technical difficulties operating this technology. This may not be surprising since Kenya is ranked 21st in the likelihood that it can adopt UAS effectively, and its weakest link as shown in the maps, is the lack of technical feasibility.

10.5 Conclusion

The analytical framework, which was developed in Chapter 5 and explored and populated in chapters 6–9, produced a ranking of 36 countries in Africa by their likelihood to successfully adopt agricultural UAS technology. Despite some limitations to this framework, it provides a useful lens through which policymakers can examine the feasibility of implementing UAS-based agricultural (and potentially other types including wildlife protection) programs. The comprehensiveness of the framework, combined with its modularity, allows for different levels of analyses. Further, its output can inform the development of concrete recommendations for policy-makers interested in adopting UAS technology in Africa, as will be discussed further in Chapter 11.
Chapter 11. Conclusion and Recommendations

This study used a mixed-method approach to investigate the feasibility—technical and non-technical—of employing UAS for agriculture in Africa. It helped fill gaps in research on this topic in three important ways: First, unlike other research on agricultural UAS uses, it is uniquely focused on Africa, the continent most plagued by food insecurity. Further, it proposed and examined two innovative delivery tasks for agricultural UAS—one in pest management of the Tsetse fly and the other in the human–wildlife conflict with the Red-Billed Quelea bird, both endemic species to Africa that undermine food security and economic development throughout the continent. In addition, rather than examining different aspects of UAS in silo, this interdisciplinary study introduced a holistic approach for assessing the feasibility of adopting this technology. Finally, the study suggested ways to detect variation in the likelihood that African countries will successfully adopt agricultural UAS.

This chapter summarizes key study findings, briefly explains the study’s strengths and weaknesses, and proposes recommendations for policymakers, experts, international organization and aid agencies interested in promoting agricultural UAS uses in Africa to enhance food security. This chapter corresponds to Phase 5 of the research plan, as highlighted in Figure 11.1:

Figure 11.1 Research Plan
11.1 Overview of Key Findings

This section reviews key study organized by corresponding research questions:

**Question 1: Can UAS Add Value to Agriculture in Africa?**

- What advanced applications of UAS improve agriculture?
- To which major African agricultural challenges can delivery missions carried out by UAS provide plausible solutions, and to what extent may these proposed UAS methods offer an improvement over currently-used technologies?

The study found that UAS can add value to agriculture. Broadly speaking, agricultural UAS are used in two main areas: surveillance (aerial imaging; remote sensing, RS) of crops and soil; and delivery or aerial application of pesticides and fertilizers over agricultural lands.

**Surveillance**

Agricultural UAS have been developed and researched predominantly, in the RS domain. UAS-mounted sensors monitor the health status of crops and soil for various reasons, for example mapping soil properties,\(^ {\text{dcxii}}\) classifying crop species,\(^ {\text{dcxiv}}\) pest management,\(^ {\text{dcxv}}\) detecting plant water stress,\(^ {\text{dcxi}}\) mapping vineyard vigor,\(^ {\text{dcxvi}}\) assessing the effects of various nitrogen treatments on crops,\(^ {\text{dcxvii}}\) detecting agricultural disease agents,\(^ {\text{dcxviii}}\) and monitoring weed control.\(^ {\text{dcxix}}\)

UAS have several important advantages over other sensor platforms. For instance, unlike satellites, UAS are not restricted by revisiting times or cloud cover conditions,\(^ {\text{dcx}}\) and they can provide ultra-high spatial resolution of images. Further, UAS are safer than manned aircraft flying in low altitudes (because aircrew is out of harm’s way),\(^ {\text{dcxii}}\) smaller classes of UAS are often more cost-effective than manned aircraft and are not restricted by scheduling of flight plans.\(^ {\text{dcxii}}\)

**Aerial Application**

Aerial application usually pertains to crop production (fertilizers) and protection materials (pesticides). Application of these materials is frequently needed at specific times and locations to increase yields or for accurate, site-specific management of crop pests.

UAS are often advantageous relatively to other technologies used for application, depending on the context. They can be more cost-effective and safer than manned aircraft.\(^ {\text{dcxiv}}\) Also, in a hilly terrain, such as the vineyard region of Northern California, UAS are considered safer, more cost-effective and accurate than tractors, and significantly less arduous than human labor.\(^ {\text{dcxv}}\) For this reason—the need to substitute human manual labor for technology—Japan adopted agricultural UAS as early as in the 1980s in response to its aging farming population.\(^ {\text{dcxvi}}\) Now, over 90 percent of crop protection in Japan is done utilizing one UAS, the Yamaha RMAX.

Notwithstanding advances in both types of agricultural UAS applications, the study found that, as in the case with other civilian and commercial UAS uses, the technology is associated with several challenges.
The most important of these include the sense-and-avoid problem; data link issues stemming from the need to communicate over long distances with aircraft flying at high speed; security threats related to risk of spoofing, hijacking, and jamming data links; and legal considerations associated with integrating UAS into national airspaces.

To explore what other UAS delivery missions could help major African agricultural challenges, this study examined two novel applications: aerial dispersal of sterile male flies in SIT programs to eradicate Tsetse flies, and as flying platforms delivering sound to scare off Red-Billed Quelea bird flocks. Results from these theoretical analyses suggest that UAS can technically perform these missions. Furthermore, in the case of the Tsetse fly, UAS may not only be more cost effective than the type of manned aircraft currently used in aerial release programs but they can also provide added value in terms of environmental damage and safety. Nevertheless, given the weight (high), altitude (low) and range (wide) requirements of aerial release in SIT programs, sUAS are not suitable to carry such missions. Instead, medium sized UAS and unmanned helicopters (that can carry a relatively large payload) are more fitting.

The challenge with such UAS types however is that they are more costly, require more operational expertise (which also means higher costs in terms of training requirements and wages), and are likely to fall under stricter legal requirements than sUAS.

The analysis also established the feasibility of using a Quelea-specific UAS that integrates visual and auditory measures to scare away flocks of the bird from farmlands. If proven effective, this technology has clear advantages over the traditional methods used for scaring Queleas—running, shouting, waving hands and throwing stones at them. Nevertheless, an experiment is necessary to examine whether the birds habituate to such a UAS over time. Further, given the enormous size of Quelea flocks, more than one UAS unit may be needed at a time, and potentially also a larger UA platform.

It is also plausible that UAS could also supplant manned aircraft to spray Quelea roosts with chemicals. In addition, UAS could serve as platforms for sensors to detect breeding colonies and roosts in preparation for control actions. The study did not thoroughly explore such applications, mostly because stakeholders in Kenya are generally against the use of lethal control methods.

**Question 2: How Are Non-Technical Factors Likely to Influence UAS Adoption in African Agriculture?**

- What key drivers/barriers are likely to promote/hinder adoption of UAS for agriculture in Africa?
- How can these drivers and barriers be modeled to assess the feasibility of adopting UAS technology for agriculture in Africa?

Overall, this study supports existing research indicating that a technical match between a technology's capabilities and a problem is necessary but not sufficient condition for the technology's adoption. Rather, adoption is influenced by multiple non-technical factors that determine whether and how the technology is adopted.\textsuperscript{dcxvii}

Two aspects of the study provide information about factors that promote or hinder technology adoption: the field study in Kenya examining the potential use of UAS for Quelea control and the
analytical framework developed to assess the feasibility of adopting UAS technology more generally across several dimensions.

Field Study
The field study in Kenya found that perspectives of farmers, and government officials and NGO staff were not necessarily consistent. For example, farmers see cost and technical difficulties (of operating UAS, charging and maintaining them) as potential barriers to adoption. But government officials and NGO personnel suggested solutions to overcome these hurdles. In addition, farmers in Kenya are not particularly concerned with privacy and security issues; however, government officials raised both as possible obstacles. Finally, given the legal vacuum in Kenya around commercial and civilian UAS, regulation may pose a hurdle in the near future. Nonetheless, government officials have proposed to facilitate an experiment to test the effectiveness of UAS for this mission to begin with and have offered support as needed.

On the other hand, the field study in Kenya identified key drivers for the adoption of UAS for Quelea control including the severe damage that Queleas inflict on crops; the absence of currently available means to mitigate the damage; stakeholders’ desire for effective, highly visible and mechanized bird control measures; and finally, the anticipated ability of UAS to draw more young people into agriculture, thereby helping to address the problem of an aging farmer population in Kenya.

Analytical Framework
The study included a comprehensive literature review and interviews with SMEs in order to assess the non-technical feasibility of employing UAS technology for agriculture in Africa more generally. The premise underlying this effort was that drivers and barriers frequently stem from the same sources, and the main difference between them lies in whether the source is available or absent. Thus, this phase of the study sought to identify the areas in which drivers and barriers lie on a continuum, albeit at different ends of the spectrum.

The study found that successful adoption of UAS for agriculture in Africa is likely to depend on the following factors:

1. Innovation capacity & technical literacy of the workforce;
2. Affordability & Economic viability;
3. Governance and institutional feasibility;
4. Cultural acceptance.

To model these dimensions, the study developed a unique analytical framework that drew from existing literature on each of these dimensions and from best practices for measuring them. When available measures were non-satisfactory, novel alternatives were proposed. For instance, to assess whether a certain country is technically capable of developing UAS in-house, the GII was modified and scaled by the number of publications published by scientists from this country in areas relevant for UAS R&D. Due to data omissions, the analytical framework was populated with data for only 36 of the 54 countries in Africa.
• Algeria
• Angola
• Benin
• Botswana
• Burkina Faso
• Burundi
• Cabo Verde
• Cameroon
• Cote d’Ivoire
• Egypt
• Ethiopia
• Gambia
• Ghana
• Guinea
• Kenya
• Lesotho
• Madagascar
• Malawi
• Mali
• Mauritius
• Morocco
• Mozambique
• Namibia
• Niger
• Nigeria
• Rwanda
• Senegal
• Seychelles
• South Africa
• Swaziland
• Tanzania
• Togo
• Tunisia
• Uganda
• Zambia
• Zimbabwe

These countries were ranked along each of the four dimensions in terms of the likelihood that they would successfully adopt agricultural UAS along the specific dimension examined. Subsequently, the four rankings were combined to a final likelihood-based ranking depicting the variation between the holistic capacities of countries to effectively adopt UAS technology for agriculture. The dimension-specific rankings were weighed equally in the production of the final ranking outcome. Figure 11.2 illustrates the steps taken in developing and populating the analytical framework.
Figure 11.2. Analytical Framework Developed for Analyzing Drivers & Barriers to Agricultural UAS-Adoption Across Africa

**Question 3: Which Countries in Africa Are Most Likely to Successfully Adopt Agricultural UAS Technology?**

- How can inter-country variation in the likelihood to successfully adopt agricultural UAS inform policymaking in this area?

The analytical framework developed to address Research Question 2 helped identify inter-country variation in the likelihood that the 36 African countries studied successfully adopt agricultural UAS technology. The modularity of this framework makes it possible to assess this likelihood along a single dimension (e.g., technical feasibility, affordability or institutional capacity); partially, integrating only a few of the four dimensions; or holistically, incorporating all dimensions. The decision about which dimensions should be used to assess the likelihood of adoption is context-dependent. For example, an international aid agency may consider funding the use of agricultural UAS in a certain country and thus may not consider affordability and economic viability at the national level, i.e., whether that country can afford to develop UAS or purchase them from abroad, as particularly relevant.

Table 11.1 presents a summary of the rankings along each dimension as well as the combined ranking in the likelihood to successfully adopt agricultural UAS at the national level. Using stoplight chart colors, the maps in Figure 11.3 offer a visual representation and a first order assessment of this inter-country
variation. The six countries ranked as most likely to successfully adopt agricultural UAS are: South Africa, Mauritius, Seychelles, Botswana, Namibia and Cabo Verde. The six countries least likely to be able to do so are: Togo, Guinea, Niger, Mozambique, Mali and Malawi. Applying the framework only to the 23 countries that neither have nor are in the process of acquiring UAS capabilities shifts the ranking. The five countries most likely to adopt UAS successfully become Mauritius, Seychelles, Namibia, Cabo Verde, and Lesotho; and the five least likely to do so are Togo, Guinea, Mozambique, Niger, and Malawi.

Table 11.1 Feasibility Rankings Along Four Pillars, and Combined; All 36 Countries

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<thead>
<tr>
<th>Affordability</th>
<th>Technical Feasibility</th>
<th>Institutional Feasibility</th>
<th>Cultural Feasibility</th>
<th>Combined Feasibility</th>
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<td>Seychelles</td>
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<td>Mauritius</td>
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Figure 11.3 Variation in Likelihood of Successful UAS Adoption; All 36 Countries
Examining the dimension-specific rankings by country can help identify the presence and scale of barriers, and accordingly prioritize the areas in which policy-makers should focus efforts to improve the likelihood of successful technology adoption. For example, Burundi is ranked low along two dimensions—35th in affordability and 33rd in institutional feasibility. It is ranked around the middle in technical feasibility (19th), and in the top third of cultural feasibility (12th). Thus, policymakers interested in promoting agricultural UAS in Burundi should focus efforts on the dimensions where the likelihood of adoption is lower, and not devote valuable resources to campaigns on dimensions where adoption seems more likely—for example, in the case of Burundi, on cultural acceptance. Concrete steps that policymakers can take to facilitate adoption of this technology are included in the recommendations outlined in the final section of this chapter.

11.2 Strengths and Limitations

This section summarizes key study strengths and limitations.

Strengths

The study’s strengths stem primarily from its original contribution to research on agricultural UAS in Africa, its interdisciplinary nature, and its innovative methodology.

The Study Fills Important Gaps in the Research Literature

The study adds to the growing body of literature on agricultural applications of UAS in more than one way. First, it is concerned with aerial application/delivery missions whereas most research in this area is about UAS surveillance tasks. Perhaps more importantly, while most agricultural UAS literature is focused on industrialized countries, this study is uniquely focused on how UAS can help promote increased food production, and alleviate hunger in Africa, the continent most affected by food insecurity. Furthermore, it proposes innovative aerial delivery tasks for UAS in response to two of Africa’s most pressing agricultural challenges—the Tsetse Fly and the Quelea bird. Finally, whereas existing research analyzes either the technical or the non-technical aspects of civilian and commercial UAS (including agricultural ones), this interdisciplinary study does both. It extends beyond the technical aspects of UAS missions, and conducts in-depth assessment of the likelihood of the technology’s adoption across different countries in Africa. In doing so, it integrates the areas of agriculture and food security, UAS and technology adoption.

The Study’s Mixed-Method Approach, Integrating Quantitative and Qualitative Analyses, Provides for Better Understanding of the Study’s Multifaceted Research Topic

The study’s mixed-method approach had five components: (1) comprehensive literature reviews; (2) in-depth interviews with various types of SMEs (Africa regional specialists, UAS and Quelea experts); (3) systems engineering approach; and (4) a field study in Kenya consisting of a smallholder farmer survey, semi-structured interviews with key informants and stakeholders along the grain production value chain in the country (other smallholder farmers, Government officials and NGO staff), and site visits. The field study enabled stakeholders to describe in their own words the problems they are facing
and the challenges and opportunities they foresee for UAS adoption in Kenya. The field study also made it possible to familiarize oneself in-person with issues on the ground not normally visible in research conducted away from the region of interest. The fifth component, a technology adoption analysis, culminated in the development of a novel analysis framework.

The Analytical Framework Is Comprehensive, Modular and Applicable to Other Topics

The original framework developed for assessing the likelihood that African countries successfully adopt agricultural UAS is comprehensive, modular and applicable to other technologies. First, it incorporates four dimensions along which countries were assessed in this study. Assessment can be conducted along a single dimension, on several dimensions, or on all four dimensions, depending on the context and the user’s objectives. Further, the framework considers the cultural acceptance dimension, which is particularly relevant for controversial technologies such as UAS; however, this consideration is not integrated into most existing frameworks. Inclusion of cultural acceptance makes this framework useful for analyzing the feasibility of adopting other stigmatized technologies, either in agriculture, e.g., GMOs, or other dual-use technologies, e.g., nuclear energy.

Limitations

The study’s limitations are of three main types: (1) the focus on only two potential missions for agricultural UAS in Africa; (2) limitations of the survey and interview data collected in the field study in Kenya to evaluate the potential use of UAS in Quelea bird control, and (3) shortcomings of the analytical framework developed for assessing the likelihood that countries in Africa successfully adopt agricultural UAS.

Narrow Focus on Aerial Application/Delivery Agricultural UAS Missions

In an effort to supplement the literature on agricultural UAS, this study examined an area less well researched—aerial application/delivery agricultural tasks that can add address major agricultural problems in Africa. It focused on two innovative uses for UAS in currently untapped fields—eradication of the Tsetse fly and Quelea bird control. However, the study did not consider other aerial application/delivery missions, e.g., crop dusting, or surveillance tasks. Thus, the generalizability of the study’s findings is limited. To partially address this limitation, Chapter 2 provides background information, reviews the literature on UAS technology in general and in agriculture in particular, and surveys some of the key limitations associated with the technology regardless of how it is used. Appendix A provides information on how RS can be used through UAS for agriculture. In addition, the framework developed to assess the feasibility of adopting UAS technology is more general and does not depend on the specific task considered—aerial application/delivery or surveillance.

Limitations of Survey and Interview Data

The survey among smallholder farmers in Kenya was conducted among a convenience sample in five rural counties and thus is not representative of the full population of interest—smallholder farmers in Sub-Saharan Africa, or even all Kenyan farmers affected by the Quelea problem. However, the sample did include female and male farmers, from various age groups, who grow different types of small crop

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grains (with an emphasis on the traditional grains—sorghum and millet), and who have been affected by the Quelea bird. Furthermore, because the Quelea is nourished on various small grain crops, some study findings may be generalizable to other smallholder farmer populations.

In addition, the samples of informants for the in-depth interviews—with SMEs, farmers, NGO staff and Government officials—were developed purposively and may not be the representative of these four populations. Moreover they do not represent all stakeholders along the small crop grain value chain—for example commercial farmers, processors, and other private sector actors. However, at the same time, this study took a first stab at holistically analyzing the suitability of UAS for Quelea control. Accordingly, it represents different geographical regions (albeit in Kenya only), various roles along the sorghum and millet crop production value chain, and key informants on the Quelea problem and on the proposed UAS-based solution. Thus, even though the data gathered may not be representative of all stakeholders, the study results are suggestive and provide valuable input for assessing if, and under what circumstances, UAS may provide a solution for Quelea control.

Limitations of the Analytical Framework
Notwithstanding the comprehensiveness of the analytical framework, it is important to acknowledge that it does not cover all elements that may influence a country’s likelihood of successfully adopting agricultural UAS. For example, the legal status of commercial UAS can either pose a barrier or serve as a driver in the technology’s adoption. However, data on the legality of UAS in most African countries are not accessible either as a result of a language barrier; or of restricted online access to legal documentation; or, as explained by Kenyan government officials, simply due to a legislative vacuum surrounding this issue. Yet, it is plausible that African governments will adopt one of the legal regimes enacted by high-income countries with UAS capabilities such as the United States, Japan, Australia and so forth. For example, in Kenya, where the government is currently in the process of drafting a law, government officials said they are using the U.S. legal framework as a model.

An additional concern is that, for analytical simplicity, the framework treats its five underlying dimensions as distinct. Nevertheless, the dimensions are likely to be interdependent. For example, a country’s openness to trade—one of the most important channels for technology transmission—depends on the domestic business climate, which in turn is influenced by the country’s culture and institutional capacity. Furthermore, the contribution of the five dimensions to a country’s capacity to adopt new technologies may not be equal and is likely to differ between countries and regions. However, to allow for general assessment for numerous countries, the framework does not address the context-dependent specific influence of each dimension per country but rather uses equal weighing of the dimensions to generate a final likelihood-based ranking. This approach is also consistent with strategies used in similar indices; it is simple; and transparent.

Finally, some of the measures of the domains within the framework are limited, as discussed in Chapters 6–10. One of these limited measures is the use of the Hofstede values to assess the extent to which countries in Africa are culturally open to foreign technologies. The Hofstede values in themselves have been criticized (e.g., based on skewed data collection) and they cover only 16 countries in Africa.
Their extrapolation to the 20 other countries of interest based on SME opinions is naturally limited due to difficulty embedded in any attempt to lump countries together.

11.3 Policy Recommendations

Drawing on the study’s findings, the following section presents a set of recommendations that could feasibly be implemented with policy changes. These recommendations are intended to address issues detected through the technical analysis, raised by a notable proportion of survey and interview participants, and identified through the analytical framework. Broadly, they can be categorized as suggestions to (1) perform mission fit analysis, i.e., carefully examine whether UAS is suitable for the agricultural mission of interest and at what cost; (2) reduce barriers and capitalize on drivers for adoption of agricultural UAS, if appropriate; and (3) conduct additional research to safely facilitate the integration of civilian UAS, including agricultural, into airspace. Within each broad recommendation I offer several more specific recommendations.

Recommendation 1: Perform Mission–Fit Analysis to Determine the Suitability of UAS for Agricultural Missions and Examine Its Associated Costs and Benefits

1.1 Carefully analyze whether UAS, and of what type of UAS, is suitable for the agricultural mission of interest, to what extent it offers an improvement over currently used methods, and the feasibility of implementing the technology.

In recent years there has been unprecedented interest in civilian and commercial UAS. In 2015, the Government in the United Arab Emirates (UAE) even launched an annual competition entitled “The UAE Drones for Good Award,” which “is dedicated to transforming the innovative technologies behind civilian drones into practical, realizable solutions for improving people’s lives today.” Agricultural UAS are featured regularly in popular media outlets and literature reviews conducted for this study indicated that the academia is also devoting greater attention to agricultural applications of UAS. In March 2015, the winner of MIT’s $100K Entrepreneurship Competition was a group that developed a ‘drone that monitors crop health to boost yields.

Nevertheless, UAS is not a panacea and it is important not to act prematurely. As this study showed, despite the hype around UAS, this technology is associated with multiple challenges (e.g., mission fit, cost, communications challenges, technical issues of operating, charging and maintaining UAS, legal hurdles, negative public perceptions and so forth). Many of these challenges become even more apparent in the context of developing countries, which are usually poor and often lag technologically.

Thus, when proposing UAS as means to address an agricultural problem, it is vital to assess whether this technology indeed offers a better solution than alternative methods, and how feasible adoption is in the local context. Such an analysis can take different forms, for instance through a systems engineering approach or by collecting survey and interview data and conducting quantitative and qualitative analysis of those data, as done in this study. Future analysis could combine both technical examination of
mission-fit and performance compared to alternatives, as well as non-technical feasibility assessment. Ideally, analysis will be based on data collected through experiments that can provide realistic estimates of the technical and non-technical issues associated with the use of this technology for a specific mission in a particular context.

For example, while UAS performing surveillance tasks can certainly add value to agriculture in Africa by providing timely data to inform a judicious use of inputs, this application might be infeasible in many areas due to a lack of supporting infrastructure, absence of technologically literate human capital, or for other reasons. In most of the rural counties visited during the field study in Kenya, there were neither electricity nor computers, and the smallholder framer population that participated in the study was not technologically savvy for the most part. While generators or batteries can overcome electricity shortages, effective use of surveillance UAS requires computers, internet connection, and people who can operate the software and interpret the data. This observation is not generalizable to all smallholder farmers in Africa or even in Kenya: infrastructure can be built and people can be trained. But it is important to consider all factors that may influence how successful the implementation of this technology can be.

1.2 Analyze all costs and benefits, both economic and non-pecuniary, of using UAS technology for agricultural missions

In connection to Recommendation 1, policymakers should conduct a thorough analysis of the projected costs and benefits of using agricultural UAS in Africa. In the case of surveillance UAS, the quality of data obtained through UAS should be compared with data availability from satellites (limited by revisiting times and cloud cover, yet free), and data quality from satellites, sensors mounted on balloons, kites, or even non-airborne or space-borne crop and soil monitoring technology. For example, the benefits of UAS may justify their use for example in vineyards in California that can leverage better data for cost savings and higher profits; however, only a marginal improvement in data quality may not justify the technology’s use in Africa, where tractors and other agricultural machinery are still scarce.

At the same time, as proposed by Kenyan Government officials interviewed for this study, such a cost–benefit analysis also needs to compare the costs of a UAS solution against the costs of the status quo. In surveillance tasks that can provide real time data on crop and soil needs, such an analysis should incorporate the costs of farming inputs (and of input subsidies if offered by the government), the availability and price of water, and environmental impacts of non-judicious input use. In the case of sUAS for Quelea control, an analysis ought to factor in current losses attributed to the Queleas and the economic and health outcomes of food insecurity resulting from the pest bird. Here again, a cost–benefit analysis should optimally be based on hard data obtained through experiments.

In addition, policymakers should consider less straightforward costs that may be associated with the use of UAS in agriculture in Africa. For instance, if considering UAS for Quelea control, it is important to assess the implications of using this technology as a substitution for human labor currently hired to scare off Queleas in regions where there is scarce employment opportunity. Such an assessment should compare the costs of lost labor against projected economic benefits for farmers (and broader food
security issues). Also, it should consider the externality imposed on other farmers if the Queleas are pushed away from one area into another that may not be protected.

**Recommendation 2: Having Identified the Potential Drivers and Barriers to Adoption of Agricultural UAS, Lower the Barriers (by Addressing Cost, Technical Issues and Cultural and Public Acceptance) and Capitalize on the Drivers (by Linking the Technology with a Broader Effort to Draw Youth into Agriculture)**

The field study in Kenya suggests that introduction of any technology to farmers is best accomplished through consultation with community leaders. In addition to general fear of change and resistance to technology, a phenomenon well documented in literature, this study found that the adoption of agricultural UAS in Africa is likely to face multiple hurdles. The following recommendations focus on objections to UAS that are fueled by fear that the technology is substituting for human labor; by negative public perceptions of risks associated with it (cultural acceptance); by concerns about affordability; and by the technical difficulty of operation or low technical literacy among the workforce (technical feasibility).

2.1 Reduce resistance to UAS adoption among those who are at risk of losing their jobs

While UAS can create new types of jobs and bring potential economic benefits, it can also, like any other technology, replace human labor. This issue is not limited to Africa. In the United States, aerial surveyors, photographers and moviemaking pilots are increasingly losing jobs to UAS. The National Agricultural Aviation Association (NAAA) Agricultural is actively lobbying to ‘protect agricultural pilots from the threat of UAVs.’ This is a dual threat—to the safety of pilots’ operating in low-level airspace, and to the job security of agricultural pilots.

Thus, if the analyses proposed in Recommendations 1 and 2 find that UAS offer a feasible solution to an agricultural problem, it is essential to address potential resistance before implementing the UAS programs, e.g., as in the case of seasonal workers hired to scare away Quelea flocks. A critical first step is to conduct a stakeholder analysis to determine who will be affected by UAS, and in what way. Subsequently, all stakeholders should be notified of the initiative and reassured that they will receive full support throughout a phased implementation process.

Whether or not the proposed UAS program is a government initiative, governmental support is critical to its success. Research on resistance to IT use in Sub-Saharan Africa has shown that governments can exert important institutional influences on adoption of innovative technologies by organizations and individuals. Government support has several aspects. First, policy makers can enact laws and regulations to authorize civilian UAS flights, which will help legitimize this technology among opponents. Moreover, because power and other major infrastructures of most developing countries are monopolized by governmental agencies, the government plays a crucial role in updating, regulating, and standardizing the infrastructure and equipment needed for UAS adoption in the long run. Furthermore, the government can provide various funding support and incentives to stimulate the use of UAS. As
proposed by a Kenyan government official, UAS for Quelea control for example can be thought of as a “public good” that would be either provided or subsidized and supported by the government. This suggestion can also help overcome barriers related to the cost of UAS and the technical difficulties of operating, charging, and maintaining the technology. In addition, the government can help create employment opportunities for those affected by the adoption of UAS, potentially related to UAS operation or maintenance.

2.2 Improve public acceptance of agricultural UAS by disassociating it from military ‘drones’
Another type of resistance to innovations is one that is fueled by technology stigmatization. The origin of stigmatization is usually marked by some significant event, accident, or reports of risk conditions. This event early on sends a very powerful signal of unusual risk. The stigma associated with UAS is mostly a result of debates about military ‘drones’ and revolve around issues of efficiency (unmanned versus manned missions), ethics (desensitized killing), and accuracy (as it pertains to collateral damage and indiscriminate civilian deaths). In addition, UAS bring about privacy concerns among individuals and groups who fear this technology would be used to spy on them.

This study confirmed that at least in the four countries subject to media analysis (Egypt, Kenya, Nigeria and South Africa), there is merit to treating UAS technology as controversial or stigmatized. The negative portrayal of the technology has several themes, all associated with the image of military “drones,” thus rendering UAS as “spying machines” or as responsible for deaths of innocent civilians, as discussed in Chapter 9. To a certain extent, the field study in Kenya confirmed this finding.

Thus, successful adoption of UAS for civilian purposes, including agriculture, will require addressing the security, safety, and privacy concerns surrounding the technology. First, it is pertinent to educate stakeholders in a transparent manner about the nature of this technology—what it can and cannot do. While UAS can indeed pose some risks (in the event that an adversary hijacks or jams the data link or if the technology misses safety features such as sense and avoid and others), the agricultural UAS proposed in this study are designed as highly visible agricultural tools that can be monitored constantly and that unless used in a hostile fighting environment, are not expected to present an unusual security risk, assuming appropriate precautions. In particular, the sUAS envisaged for Quelea control will mimic the physical features of a predator bird, emit bioacoustics sounds, and fly at low altitudes to scare away Quelea flocks from farms. This is in line with the preferences of farmers surveyed for highly visible mechanic means of Quelea control. The MALE UAS class found suitable for Tsetse eradication is relatively large and the altitude at which it is to fly for this mission is 328 ft., making it extremely noticeable. The Agricultural UAS for surveillance mostly conduct low altitude remote sensing (LARS) missions that complement remote RS of high-altitude flights from piloted aircraft and satellite. Hence, these are also very discernible machines. These typically belong to sUAS class and cannot carry a heavy payload weight like a bomb as feared by some.

Second, it is important to distinguish agricultural UAS technology from its military counterparts both in design and in the way the technology is introduced to the public, either through a targeted education
campaign or/and through the media. A design using bright colors and other distinct features would make agricultural UAS deliberately highly noticeable, thus eliminating the secrecy associated with military UAS. In introducing agricultural UAS to the public, government support can also play a nuanced moderating role. By enacting policies and leveraging public media, the government can help nurture an innovation-oriented national culture\textsuperscript{36} in which UAS are portrayed as a tool to aide agriculture and help alleviate food insecurity. Doing this will reduce the perceived threat associated with UAS as a military technology and highlight its benefits instead. Finally, policymakers seeking to adopt agricultural UAS may even consider discarding the term “drones” to describe this technology.

2.3 Consider different implementation models to lower costs and technical barriers

Two of the most obvious obstacles to agricultural UAS adoption in Africa identified in this study are the technology’s cost and the difficulty of operating it. Clearly, smallholder farmers cannot afford UAS technology. What is more, many of them are not technically literate and can find operating UAS impossible. To overcome these barriers, various implementation models should be considered, depending on the context. They should assess the type of agricultural mission, cost of the potential UAS solution, geographical range, countries involved (and their national wealth), and so forth. Under different implementation designs, smallholder farmers can either be end-users (if the technology is subsidized) or customers (if a national government, NGO, an IGO or a private entity provides services employing UAS based on need).

For example, just as the Tsetse eradication effort in Senegal is managed by the FAO, the United States, France, and the Senegalese government, any large scale UAS program will require domestic and international funding and support. In addition, considering that manufacturers of agricultural UAS are likely to come from foreign companies, there is reason to suggest a greater role for the private sector in promoting technology adoption.\textsuperscript{37}

As NGO staff proposed regarding UAS for Quelea control, implementation may involve their organization as sponsors of such UAS programs or as providers of bird-control services in times of need. Government can offer to subsidize this technology for a community-based sharing model or the provision of this service, similar to farming input subsidies. Using UAS platforms for multiple missions (e.g., monitor crop and soil conditions when not scaring off birds) can make this technology more appealing for government and NGO funding. In addition, the implementation design should explore potential private–public partnerships between processors and government. In the context of Quelea control, these may be breweries that purchase sorghum from smallholder farmers. Others processors may include chocolate producers interested in ensuring constant supply of quality grade cocoa beans and so forth.

Involvement of a national government, IGO, NGO or the private sector also addresses the technical challenges associated with operating, maintaining and charging UAS because trained personnel will assume these tasks. The design of the implementation model should be based on cost–benefit analysis as well as stakeholder analysis as proposed in Recommendations 2 and 3, respectively.
2.4 Capitalize on drivers to UAS adoption

One of the most important drivers identified in Chapter 4 as a potential enabler of UAS for Quelea control is the projected power of UAS to draw youth into agriculture. Hence, informational and media campaigns on agricultural UAS should not only emphasize the potential positive effect UAS can have on agriculture and food security, and the unique solution this technology provides, but should also highlight that using UAS may help reverse the alarming trend of an aging farmer population.

To demonstrate this opportunity, implementers of agricultural UAS initiatives should consider developing training programs for young members of communities in which the technology is to be employed. This recommendation is based on recent developments in farming support in Africa, part of which is that agricultural research and advisory services are increasingly channeled through farmer groups. From the government or donor perspective, these groups create an efficient channel for engaging a particular target group in a development program. Further, working with these communities makes training and dissemination more efficient.

Another advantage of the farmer-group level in adoption of new technologies is that in the event that a group decides to purchase a technology, trainers in the community can be selected from among the farmers themselves, who then act as para-professionals in operating and maintaining the technology. As demonstrated in previous research, such trainers are the community’s reference teachers. They understand the farmers better because they are themselves part of the community. In addition, even if a technology is purchased by an organization other than the group itself—be it government, an NGO or an IGO—such trainers can play a key role in linking farmers and the development agencies staff, making it easier to build the capacity of many farmers within a short time and simultaneously drawing more young people who were not interested in manual farming into exciting opportunity to fly UAS and help their community.

Recommendation 3: Future Research Funds Should be Devoted to Particular Areas that Can Improve Understanding of the Technical and Non-Technical Feasibility of Employing Agricultural UAS Across Africa

This dissertation is intended as an exploratory study of the feasibility of employing agricultural UAS across Africa. The results of this study suggest that UAS may indeed help alleviate some of Africa’s agricultural challenges; however, adoption of the technology is likely to face several hurdles, both technical and non-technical. Additional research will help policymakers better understand the multifaceted ramifications of agricultural UAS in the context of Africa and identify ways to address these challenges. The discussion below suggests areas of further research to (1) overcome some of the key technical challenges associated with civilian and commercial UAS technology (communications, integration into airspace etc.); (2) explore additional aerial application/delivery as well as surveillance tasks for agricultural UAS in Africa; and (3) improve the framework to assess the likelihood that countries in Africa successfully adopt this technology.
1. Technical challenges of civilian UAS, including agricultural

There is consensus that additional research is needed to overcome technical adoption challenges that may hinder widespread use of UAS in civilian airspace, for agricultural missions or for other. These challenges include:

- **Data link challenges**: Designing aeronautical wireless data links is challenging due to the large distances that these links need to cover and the high-speed of the aircrafts. These requirements, along with the limited availability of RF spectrum, affect the performance of the data link. More research is needed regarding the development of new data links for commercial and civilian UAS before they share non-segregated military-civilian airspace.\(^{dcxxix}\) In addition, to make the communications system foolproof, security features can be built into the system. For example, one approach is for the aircraft to acknowledge or echo all commands it receives so that the operator can be notified if it receives commands from an unauthorized entity.\(^{dcx}\) The military uses secure data links with built-in validating functions, but no such solution is available yet for the civilian market. This area must be explored.\(^{dcx}\)

- **Sense and avoid**: Even though significant research is currently being conducted on the UAS sense and avoid problem,\(^{dcxii}\) additional research is needed in this critical area. Active solutions include the use of radar or Traffic Collision Avoidance System to detect collision threats; however such solutions require large amounts of electrical power, and are heavy (more than 44 lb.). Thus they may not be suitable for large parts of Africa. Passive solutions include the use of machine vision, which would reduce the power requirement, yet requires high computational capability, which again may pose a problem across Africa.

- **Lost link procedures**: UAS must be provided with a means of automatic recovery in the event of a lost link. These procedures are part of a larger fault monitoring mechanism to ensure that undetected system faults will not lead to catastrophic system failure, potentially leading to human casualties on the ground. Catastrophic system failure could also lead to loss of costly UAS technology, an important consideration in Africa, where affordability may pose a constraint for UAS adoption to begin with. More research is needed to determine the best approach to satisfy this requirement and ensure airborne operations are predictable in the event of lost link.\(^{dcxiii}\)

- **Autonomous operations**: The trend in UAS research is toward developing more autonomous systems.\(^{dcxiv}\) A high degree of autonomy may be desired for agricultural tasks in Africa, where technical literacy may be lower than in the United States and in other developed countries. At the same time, such systems are likely to be more expensive, associated with additional operational challenges, and more controversial in the eyes of the public and policymakers. Therefore, additional research is needed on the implications of increased UAS autonomy in civilian applications and how these implications can be addressed in the African context.

In addition, because most of the research on UAS is done within and on industrialized countries with crowded airspace, it would be useful to map the landscape of national airspaces in Africa. On one hand, a non-crowded airspace can mitigate the need for perfect sense-and-avoid mechanisms; however, such airspace is also likely to be poorly regulated and thus may be more prone to security threats including spoofing, hijacking, and jamming the data link.
2. Research on additional tasks for agricultural UAS in Africa

To fully capture the potential opportunities and challenges associated with the use of agricultural UAS in Africa, more research is needed to determine whether this technology can offer a solution to problems other than the Tsetse fly and the Quelea bird. Aerial application/delivery tasks can include UAS for crop dusting or irrigation. On the other hand, a surveillance task of prime importance is monitoring soil moisture. The ability to obtain accurate and timely information on soil characteristics can be of potential great interest for the arid African countries that comprise 60 percent of the continent’s landmass. Both satellite and manned aircraft have shortcomings in terms of their ability to assist in obtaining timely and accurate information via sensors. UAS may be advantageous in comparison with these in platforms and prove suitable for microwave and optical sensors that can collect data on soil characteristics.

A hybrid type of mission for example is precision agriculture (PA). Also known as information-based management of agricultural production systems, PA refers to two segments of the farm market: RS (a variety of remote sensors are used to scan plants for health problems, record growth rates and hydration, and locate disease outbreaks), and precision application (precision application utilizes effective and efficient spray techniques to more selectively cover plants and fields). This combination allows farmers to provide only the needed pesticide or nutrient to each plant, lowering the total amount sprayed, thus saving money and reducing environmental impacts. These advantages make UAS potentially beneficial for the resource-constrained African agricultural landscape characterized by small plots on which different varieties of crops are grown simultaneously, however, current research on this prospect is still lagging.

3. Improve the framework assessing the likelihood that countries successfully adopt UAS

Finally, while the framework developed to assess the likelihood that African countries successfully adopt agricultural UAS offers a useful lens through which policymakers can make such an assessment, more research is needed to test and improve it. For example, to examine the extent to which technology in general is accepted across Africa, more research is needed to develop better measures than the Hofstede Dimensions used in this study. In addition, unless Hofstede covers other countries of interest in the future, additional research may use a different cultural measure that spans a larger number of countries in Africa. Finally, to supplement assessments of general cultural acceptance of technology, such as the one undertaken by Hofstede, future research should investigate UAS-specific acceptance. The present study tackled this limitation by a small-scale media analysis that, while useful, suffered from several shortcomings. To better understand the media’s portrayal of UAS in the four countries discussed as well as in other African countries, a more in-depth media analysis is needed that would address those shortcomings, i.e., it will cover a larger number of newspapers from each country; will analyze English and non-English items; and will draw from internet sources as well as from print newspapers not available online, radio and television clips, and even social media content. Finally, to ensure media analysis reflects public sentiment, such analysis should be backed by country-specific surveys and, as needed, focus groups.
Appendix A. Remote Sensing & agricultural applications

A.1 Introduction

Remote sensing (RS) is a promising avenue for agricultural development in Africa. As discussed in Chapter 1: Introduction, growing food demand on one hand, coupled with dwindling natural resources and climate change threats on the other, underscore the need to embrace new farming technologies that could boost crop yields in an environmentally sustainable manner. While the analyses in this study focus on aerial delivery applications of UAS, it is important to acknowledge that most agricultural UAS applications are in the field of RS. And even though African agriculture is currently lagging behind in mechanization and utilization of data, the continent can find important farming uses for UAS mounted with sensors. Thus, it is first useful to understand the basics of RS and how it is used in agriculture more generally. To do so, this appendix opens with background information on optics and RS principles. It continues with technical discussion on different types of RS (optical, infrared and microwave). Finally, it explains how RS technologies are used in agriculture.

A.2 Background: Remote Sensing Basics

Remote sensing refers to activities of obtaining information about a distant object, phenomenon or area through analysis of data acquired by a device that is not in contact with the object, phenomenon or area investigated. The human eye for example is such a device which helps people to conduct countless remote sensing activities every day including reading, watching people and cars on the road, sightseeing and more. The process begins with the eye registering the solar light reflected by an object. Then, the brain interprets the colors, grey tones and intensity variations, and these data are translated into useful information.

More restrictively, remote sensing alludes to acquisition and analysis of electromagnetic radiation by sensors onboard airborne or spaceborne platforms. While the human eye is limited to a small part of the total electromagnetic spectrum i.e. approximately 400 to 700 nm, sensors can detect electromagnetic energy outside this range, especially the near infrared, middle infrared, thermal infrared and microwaves. Figure A.1 shows the electromagnetic spectrum.
Thus, electromagnetic remote sensing can be divided into two processes: data acquisition and data analysis. In the former, sensors record variations in reflectance and emission of electromagnetic energy by objects. In the latter, the data is examined with the aid of viewing and interpretation techniques and reference data, assessed, compiled and presented to users. Table A.1 lists the elements and steps associated with these two primary processes.

Table A.1. Data Acquisition and Data Analysis: Elements and Steps

<table>
<thead>
<tr>
<th>Data Acquisition</th>
<th>Data Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Energy sources.</td>
<td>(g) Analysis of pictorial/digital sensor data using viewing and interpretation technologies.</td>
</tr>
<tr>
<td>(b) Propagation of energy through the atmosphere.</td>
<td>(h) Reference data (soil maps, crop statistics etc.) assist in analysis.</td>
</tr>
<tr>
<td>(c) Energy interactions with surface features.</td>
<td>(i) Information on type, extent, location and condition of object/area investigated is compiled and can be merged with other types of information (GIS).</td>
</tr>
<tr>
<td>(d) Retransmission of energy through the atmosphere.</td>
<td>(j) Information is presented to users and utilized by decision-makers.</td>
</tr>
<tr>
<td>(e) Airborne/spaceborne- mounted sensors.</td>
<td></td>
</tr>
<tr>
<td>(f) Pictorial/digital representation of sensor data.</td>
<td></td>
</tr>
</tbody>
</table>

When sensors are mounted on high altitude platforms, the electromagnetic radiation from Earth surface is affected by the atmosphere. Specifically, it may be absorbed or scattered by the constituent particles of the atmosphere, where absorption converts the radiation energy into excitation energy of the molecules, and scattering redistributes the energy of the incident beam to all directions. The overall effect is the removal of energy from the incident radiation.
Certain wavelength bands in the electromagnetic spectrum are strongly absorbed and effectively blocked by the atmosphere. The wavelength regions in the electromagnetic spectrum usable for remote sensing are determined by their ability to penetrate atmosphere. These regions are known as the atmospheric transmission windows. These windows exist in the microwave region, some wavelength bands in the infrared, the entire visible region and part of the near ultraviolet regions. Remote sensing systems are often designed to operate within one or more of those atmospheric windows to minimize the atmospheric absorption effects. Atmospheric effects also degrade the image quality (some of which can be repaired in the processing stage).

A.2.2 Types of RS

Remote sensing is divided to three main categories: optical, infrared, and microwave.

A.2.2.1 Optical RS

Optical RS depends on the sun as the sole source of illumination. When solar radiation hits a target surface, it may be transmitted, absorbed or reflected. Some materials will reflect certain wavelengths of
light, while other materials will absorb the same wavelengths. The reflectance spectrum of a material is a plot of the fraction of radiation reflected as a function of the incident wavelength and serves as a unique signature for the material. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient spectral resolution to distinguish its spectrum from those of other materials.

The reflectance of clear water is generally low however the reflectance is at its peak at the blue end of the spectrum and decreases as wavelength increases therefore clear water appears dark-blue. Turbid water has some sediment suspension which increases the reflectance in the red end of the spectrum, resulting in its brown-like color. The reflectance of soil depends on its composition. In the examples shown, the reflectance of both dry and wet soils increases monotonically with wavelength hence appearing yellow-red to the human eye. Vegetation has a unique spectral signature which distinguishes it fairly easily from other types of land cover in optical/near-infrared imagery. The reflectance is low in both the blue and red regions of the spectrum, due to absorption by chlorophyll for photosynthesis. It has a peak at the green region which explains its green color of vegetation. Moreover, the reflectance in the NIR region is much higher than that in the visible band enabling to identify vegetation by the high NIR. The shape of the reflectance spectrum can help distinguish between vegetation types. For example, the reflectance spectra of Needleleaf and broadleaf vegetation in Figure A.4 can be distinguished although they exhibit the same characteristics of high NIR but low visible reflectance. The broadleaf vegetation has higher reflectance in the NIR region. Within the same vegetation type, the reflectance spectrum also depends on other factors such as the leaf moisture content and health of the plants.

Figure A.4 Spectral reflectance signature (typical reflectance spectra of eight earth features)

Optical RS Imagery Systems
Optical RS uses visible, near infrared and short-wave infrared sensors to detect solar radiation reflected from targets and form images. Optical RS systems are classified into the following four types, depending on the number of spectral bands used in the imaging process.
1. **Panchromatic**: The sensor is a single channel detector sensitive to radiation within a broad wavelength range. If the wavelength range coincides with the visible range, then the resulting image resembles a “black-and-white” photograph taken from above. Thus, a panchromatic image may be similarly interpreted as a black-and-white aerial photograph of the area. The Radiometric Information is the main information type utilized in the interpretation. The physical quantity being measured is the apparent brightness of the targets. A panchromatic image consists of only one band. It is usually displayed as a grey scale image.

2. **Multispectral**: The sensor is a multichannel detector with a few spectral bands. Each channel is sensitive to radiation within a narrow wavelength band. The resulting image is a multilayer image which contains both the brightness and spectral (color) information of the targets being observed. Each band of the image may be displayed one band at a time as a grey scale image, or in combination of three bands at a time as a color composite image. The basis for multispectral RS is the distinguishable nature of spectral reflectance signatures which allows for differentiation between materials. A multispectral system usually provides a combination of visible (0.4 to 0.7 µm), near infrared (NIR; 0.7 to 1 µm), short-wave infrared (SWIR; 1 to 1.7 µm), mid-wave infrared (MWIR; 3.5 to 5 µm) or long-wave infrared (LWIR; 8 to 12 µm) bands into a single system.

3. **Superspectral**: Superspectral imaging sensors consist of more than ten spectral channels. The bandwidths are narrower than in multispectral sensors which help to capture the finer spectral characteristics of the features that are captured by the sensors. Superspectral imaging sensors are less common than the other types.

4. **Hyperspectral**: Hyperspectral imagery is characterized by many narrow and contiguous spectral bands, which allows for acquisition of detailed spectra for each pixel in an image. Although most hyperspectral sensors measure hundreds of wavelengths, it is not the number of measured wavelengths that defines a sensor as hyperspectral. Rather it is the narrowness and contiguous nature of the measurements. Hyperspectral imagery provides the potential for more accurate and detailed information extraction than possible with any other type of remotely sensed data. In agriculture, detecting subtle differences in reflection and absorption patterns can help identify individual species, lead to higher mapping accuracies, and other precision farming applications.

In displaying multispectral, superspectral and hyperspectral imaging, three primary colors (red, green and blue) are combined in various proportions to produce different colors in the visible spectrum. The association of each spectral band with a separate primary color results in a color composite image. The three primary color bands may be combined to produce a “true color” image or arbitrarily resulting in “false color” images, which do not resemble the targets’ actual colors. A common false color composite for example allows vegetation to be detected readily and distinguished according to its types and conditions. Some sensors lack one or more of the three visual primary color bands and then the spectral bands are often combined to produce an image that resembles the “true” colors of the target. Such images are known as “natural color composites.”

In addition to color, texture is important in visual image interpretation, especially for high spatial resolution imagery. It is also possible to characterize the textural features numerically, and algorithms for automatic differentiation of textures are being utilized regularly.
A.2.2.2 Infrared RS

Infrared sensors detect infrared radiation emitted from objects. The amount of thermal radiation emitted at a particular wavelength from a warm object depends on its temperature. The middle-wave infrared (MWIR) and long-wave infrared (LWIR) are within the thermal infrared region. These radiations are emitted from warm objects such as the Earth’s surface. A series of satellite and airborne sensors have been developed for example to collect thermal infrared (TIR) data to detect fires, as well as land surface temperature (LST) which is used in conjunction with emissivity data in urban climate and environmental studies.dclxiv

Figure A.5 Grass Valley fire near Lake Arrowhead in the San Bernardino Mountains of Southern California, October 2013.

A.2.2.3 Microwave RS

Microwave RS includes both active and passive forms of remote sensing. Microwaves’ long wavelengths can penetrate through cloud cover, haze, dust, and all but the heaviest rainfall because longer wavelengths are not susceptible to atmospheric scattering which affects shorter optical wavelengths. This property allows detection of microwave energy under almost all weather and environmental conditions so that data can be collected at any time.

Passive microwave sensing

Similar to thermal remote sensing. A passive microwave sensor detects the naturally emitted microwave energy within its field of view. This emitted energy is related to the temperature and moisture properties of the emitting object or surface. Passive microwave sensors are typically radiometers or scanners and an antenna is used to detect and record the microwave energy. The microwave energy recorded by a passive sensor can be emitted by the atmosphere (1), reflected from the surface (2), emitted from the surface (3), or transmitted from the subsurface (4). Because the wavelengths are so long, the energy available is quite small compared to optical wavelengths. Thus, the fields of view must
be large to detect enough energy to record a signal. Most passive microwave sensors are therefore characterized by low spatial resolution. Applications of passive microwave remote sensing include meteorology, hydrology, and oceanography.

Active microwave sensing
Active microwave sensors provide their own source of microwave radiation to illuminate the target. Such sensors can be divided into two categories:

Imaging
The most common type of imaging active microwave sensors is RADAR (Radio Detection And Ranging). A RADAR sensor transmits a microwave (radio) signal toward the target and detects the backscattered portion of the signal. The strength of the backscattered signal is measured to discriminate between different targets and the time delay between the transmitted and reflected signals determines the distance (or range) to the target. Radar has two primary advantages: it can be used to image a target or surface at all weather, as well as at any time, day or night.

In radar imaging, the ground resolution is limited by the size of the microwave beam sent out from the antenna. The beam width is inversely proportional to the size of the antenna. Thus, higher resolution of targets requires longer antennas, but spacecraft and aircraft are limited by the size of antennas they can carry. To overcome this limitation, synthetic aperture radar (SAR) imaging was developed. The SAR uses the RADAR principles but also takes advantage of the motion of the platform (spacecraft, aircraft) to emulate a large antenna.

Non-imaging
Non-imaging microwave sensors include altimeters and scatterometers. Radar altimeters transmit short microwave pulses and measure the round trip time delay to determine their distance from the sensor. Generally altimeters look straight down at nadir below the platform and are used on aircraft for altitude determination and on aircraft and satellites for topographic mapping and sea surface height estimation. Scatterometers are used to make precise quantitative measurements of the amount of energy backscattered from targets, which is dependent on the surface properties and the angle at which the microwave energy strikes the target.

A.3 Agricultural Applications of RS
Agricultural RS is not new and dates back to the 1950s. The attributes of RS as non-disruptive means to collect systematic, accurate, timely information are advantageous in the area of agriculture. As pointed out by the FAO, the need for timeliness is a major factor underlying agricultural statistics and associated monitoring systems for sever reasons. First, the seasonal patterns of agricultural production justify the need for ongoing monitoring of crops, soil, climatic conditions and agricultural management practices. Moreover, as productivity can change within short time periods, due to unfavorable growing
conditions, agricultural monitoring systems need to be timely. This is even more important because many agricultural products are perishable.

Recent technological advances have made the benefits of RS more accessible to agricultural producers. Sensors mounted on aircraft, satellite, and ground-based platforms obtain information on crop and soil characteristics. This information in turn can be used to identify nutrient deficiencies, diseases, water status, weeds, damages, and plant populations. This section focuses on the main agricultural applications of RS, and specifically explains how this technology can help to assess plant stress, perform crop type mapping, measure soil moisture, estimate crop yield, and support precision agriculture (PA) practices.

A.3.1 Detecting Plant Stress

One of the key agricultural applications of RS is crop condition assessment and detection of plants’ stress resulting crop disease, insect damage, disaster damage and other causes. It is based on the biological principle according to which carbohydrates are produced by combining light, carbon dioxide and water through the process of photosynthesis. The general equation for this process is:

\[
6\text{CO}_2 + 6\text{H}_2\text{O} + e \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + e
\]

**Carbon dioxide + Water + Absorbed EM radiation** \(\rightarrow\) **Glucose + Oxygen + reflected EM radiation**

Monitoring the radiation that is reflected by a plant provides insights into how efficiently it is carrying on photosynthesis and hence into its general state of health.

Photosynthesis occurs in chloroplasts, specialized chlorophyll-containing plant cells that are most abundant in plant leaves. During photosynthesis, chloroplasts absorb blue and red light and reflect green light so chlorophyll-containing leaves appear green in color. Reduction in the number of chloroplasts results in a decrease in the amount of red radiation that the plant absorbs therefore as plants die, they begin to brown and the amount of red radiation that they reflect increases. Photosynthetically-active plant leaves also strongly reflect radiation of 700–1,000 nm in the NIR portion of the spectrum.

In addition to chloroplasts, chromoplasts represent another specialized type of plant cell that interacts with specific wavelengths in the electromagnetic spectrum. Chromoplasts synthesize and store pigments such as orange carotene, yellow xanthophylls, and various red pigments. The color of the chromoplast varies depending on the pigment it contains. Like chloroplasts, these cells also impart colors to the parts of the plant that contain them.
Chromoplasts are present with chloroplast cells in leaves, fruits, flowers and some roots. As the ratio of chloroplasts to chromoplasts changes in a plant structure, that part of the plant changes color. It is the increase in the number of chromoplast cells to chloroplast cells in a lemon, for example, that is responsible for the fruit changing color from green to yellow during ripening. The changing ratio of chloroplast to chromoplast cells that is responsible for plant leaves changing color from green to red, orange or yellow as a result of changing seasons.

In general, the relationship between reflected, absorbed and transmitted energy is used to determine spectral signatures of individual plants. Spectral signatures are unique to plant species and are used to indicate plants’ stress. To identify stress areas by RS, it is first necessary to establish the spectral signatures of healthy plants. The spectral signatures of stressed plants appear altered from those of healthy plants. Interpreting the reflectance values at various wavelengths of energy can be used to assess crop health.

Vegetation Indices

Using the ratio of reflected infrared to red wavelengths as a measure of vegetation health has been the premise behind some vegetation indices developed to quantify healthy vegetation in images. The simplest and most popular index is the normalized differential vegetation index (NDVI), which contrasts the radiation reflected from healthy vegetation at each pixel location in an image with radiation reflected from all other sources. Table A.2 lists the most popular vegetation Indices, including NDVI.

<table>
<thead>
<tr>
<th>Vegetation Index</th>
<th>Formula</th>
<th>Bands</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI (Normalized Difference Vegetation Index)</td>
<td>$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$</td>
<td>NIR and RED</td>
</tr>
<tr>
<td>RVI (Ratio Vegetation Index)</td>
<td>$\text{RVI} = \frac{\text{NIR}}{\text{RED}}$</td>
<td>NIR and RED</td>
</tr>
<tr>
<td>NDWI (Normalized Difference Water Index)</td>
<td>$\text{NDWI} = \frac{\text{NIR} - \text{SWIR}}{\text{NIR} + \text{SWIR}}$</td>
<td>NIR and SWIR</td>
</tr>
<tr>
<td>SAVI (Soil Adjusted Vegetation Index)</td>
<td>$\text{SAVI} = \frac{(1 + L) \times \text{NIR}}{\text{NIR} + \text{RED} + L}$</td>
<td>NIR and RED</td>
</tr>
<tr>
<td>TVI (Triangular Vegetation Index)</td>
<td>$\text{TVI} = 0.5 \times (120 \times (\text{NIR} - \text{GREEN}) - 200 \times (\text{RED} - \text{Green})$</td>
<td>NIR, RED and GREEN</td>
</tr>
<tr>
<td>TNDVI (Transformed Normalized Difference Vegetation Index)</td>
<td>$\text{TNDVI} = \left(\frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED} + 0.5}\right)^{0.5}$</td>
<td>NIR and RED</td>
</tr>
</tbody>
</table>

Source: FAO

From the NDVI formula equation, it is easy to see that NDVI is an index that varies from +1 to −1. Healthy plants have a high NDVI value because of their high reflectance of infrared light, and relatively low reflectance of red light.
A.3.2 Crop Type Classification

Identifying and mapping crops is important for forecasting grain supplies (yield prediction), collecting crop production statistics, mapping soil productivity, identification of factors influencing crop stress, assessment of crop damage due to storms and drought, and monitoring farming activity.

Traditional methods of crop type classification are census and ground surveying. RS however offers an efficient and reliable means of collecting the information required, in order to map crop type and extent (often measured in acres of meters).

Crop type classification is based on the premise that specific crop types can be identified by their spectral response patterns and photo textures. The spectral reflection of a field will vary with respect to changes in the phenology (growth), stage type, and crop health. Thus, multispectral sensors provide an advantage over panachromatic ones. Radar is sensitive to the structure, alignment, and moisture content of the crop, and thus can provide complementary information to the optical data. Combining the information from these two types of sensors increases the information available for distinguishing each target class and its respective signature, and thus there is a better chance of performing a more accurate classification.\(^{dclxxii}\)

In addition, in areas of persistent cloud cover or haze, radar is useful for observing and distinguishing crop type. Its active sensing capabilities and long wavelengths are capable of penetrating through atmospheric water vapor. For example, radar is helpful in monitoring the development of rice paddies, which is characterized by a substantial change in brightness comparing the low returns from smooth water surfaces in flooded paddies, to the high return of the emergent rice crop.\(^{dclxxiii}\)

Successful identification of crops requires knowledge of the developmental stages of each crop in the area that is inventoried. Because of changes in crop characteristics during the growing season, crop mapping benefits from use of multi-temporal imagery to facilitate classification by taking into account changes in reflectance as a function of plant phenology (stage of growth). This in turn requires calibrated sensors, and frequent repeat imaging throughout the growing season.\(^{dclxxiv}\)

A.3.3 Measuring Soil Moisture

Measuring soil moisture is an important measure in determining crop yield potential in in drylands and drought-affected parts of the world, including Africa. The moisture content generally refers to the water contained in the upper 3–6 ft. of soil, which can potentially evaporate into the atmosphere. Early detection of dry conditions that could damage crops, or that are indicative of potential drought, is important for amelioration efforts and forecasting potential crop yields.

Unlike ground measurements that are inherently restricted to discrete point locations, RS provides a means of measuring soil moisture across a wide area.

Radar is effective for obtaining qualitative imagery and quantitative measurements, because radar backscatter response is affected by soil moisture, in addition to topography, surface roughness and
amount and type of vegetative cover. Frequent and regular (repeated) imaging is required during the growing season to follow the change in moisture conditions, and a quick turnaround is required for a farmer to respond to unsuitable conditions (excessive moisture or dryness) in a timely manner. Using high resolution images, a farmer can then target irrigation efforts more accurately.

The data requirements for assessing soil moisture vary by land plot sizes. While in the United States there is no need for particularly high resolution data, the small plot sizes of Africa’s farms necessitate higher resolution data.\textsuperscript{dclxxv}

\textbf{A.3.5 Crop Yield Estimation}

Reliable estimates of crop yields are important planning tools not only for farmers but also for national and international agricultural agencies, insurance agencies, commodity brokers and international humanitarian agencies which rely on early and reliable crop information to organize response interventions. The earlier in a growing season that an accurate yield prediction can be made, the more useful the analysis will be.

Coarse scale crop monitoring and yield estimation employ techniques that can be simplistically be divided into three main groups: qualitative crop monitoring, quantitative crop yield predictions by regression modeling; and quantitative yield forecasts using (mechanistic and dynamic) crop growth models.

Qualitative (or semi-qualitative) crop monitoring methods use low resolution imagery to derive indicators that can attest to crop growth conditions. In general, these methods are based on the comparison of the actual crop status to previous seasons or to what can be assumed to be the average. Detected anomalies are then used to draw conclusions on possible yield limitations. Vegetation indices, most prominently the normalized difference vegetation index (NDVI), are used in this group of techniques to study crop status.\textsuperscript{dclxxvi}

Quantitative crop yield predictions use regression models. Unlike qualitative approaches, the regression approaches must be calibrated using appropriate reference information. In most cases, agricultural statistics and, specifically, crop yield are used as reference information. Those approaches are either purely based on RS or mixed and include additional bio-climatic predictor variables. This section only introduces the former.

Yield is mainly a function of photosynthesis in agricultural plants in periods prior to harvest. Thus, the relationship between vegetation indices and biomass/ Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) enables the early estimation of crop yield.\textsuperscript{dclxxvi} In general, these regression models use NDVI as an independent variable to estimate final crop grain yield, which is the dependent variable. The basic assumption of this method is that sufficiently long and consistent time series of both RS images and agricultural statistics are available. Where the crop area is not known, the NDVI/yield relationship does not provide information on final crop production. For this reason, NDVI is sometimes used to predict final crop production directly or to estimate the fraction of NDVI inter-annual variability.
due to changes in crop area. In general, a direct NDVI/production regression makes only sense under specific conditions, such as a stable crop area over the observed period.\textsuperscript{dclxxvii}

Finally, crop monitoring and yield predictions can also be based on modeling of crop physiology. The techniques under this approach are varied and depend on the level of detail with which crop physiology is modeled. In general, the models describe the primary physiological mechanisms of crop growth (e.g., phenological development, photosynthesis, dry matter portioning and organogenesis), as well as their interactions with the environmental. Remotely-sensed information is utilized in various ways, for example to measure the amount of photosynthetically active solar radiation (PAR) absorbed, on which the biomass production of a crop depends.\textsuperscript{dclxxix}

Important crop parameters for yield estimation are arithmetic combinations of red and near infrared areas reflectances, also known as the vegetation indices.\textsuperscript{dclxxx} For example, the NDVI is commonly used as an indirect measure of primary land productivity. Research in vegetation monitoring has shown that NDVI is closely related to the leaf area index (LAI) and to the photosynthetic activity of green vegetation. Moreover, NDVI is an indirect measure of primary productivity through its quasi-linear relation with the fAPAR (Fraction of Absorbed Photosynthetically Active Radiation).

\textbf{A.3.5 Supporting precision agriculture practices}

Precision agriculture is an integrated, information- and production-based farming system that is designed to increase long term, site-specific and whole farm production efficiency, productivity and profitability while avoiding the undesirable effects of excess chemical loading to the environment or productivity loss due to insufficient input application. PA is based on RS in combination with other technologies such as Geographic Information System (GIS), Global Positioning System (GPS), computer modeling, variable rate technology and advanced information processing.\textsuperscript{dclxxxi} PA utilizes the aforementioned agricultural applications especially:\textsuperscript{dclxxxi} Crop information (growth stage, health, nutrient requirement), soil properties, depth (moisture, texture, nutrient status, salinity and toxicity, temperature, productivity potential); and microclimatic data (such as canopy temperature, wind direction and speed, and humidity).

Information gathered through different sensors and referenced using a GPS can in turn be integrated to create field management strategies for chemical application, cultivation and harvest. Although RS may not capture all types of agricultural data, it can reliably provide accurate and timely information to guide farming decision-making.
Appendix B. Interview Protocol: Red-Billed Quelea Subject Matter Experts

1. What is the estimated damage caused by the Quelea bird?
2. Which crops in your opinion are at most risk of the Quelea bird?
3. In your view, has the bird influenced farmers’ behaviors and attitudes? If so, how?
4. How is Quelea problem being addressed currently in this area?
5. How effective are such methods?
6. This study is examining the feasibility of using an unmanned aerial system (UAS; also known as drone) to scare off flocks of Quelea. The UAS will visually be similar to a Quelea predator and mounted with a bioacoustics device that will mimic the Quelea distress sounds.
   - Do you know what a drone is? If yes, move on. If not, I will provide an explanation.
   - What birds are the Quelea’s main predators?
   - What sounds do Queleas make when they are distressed or alarmed and can we record/mimic them?
   - What is your view on using a drone to scare off the Quelea flocks—how effective? Feasible? Culturally acceptable?
7. Another thought is to use the UAS to draw the flocks to a place where they can be trapped and later on cooked to provide a nutritious source of protein.
   - What mechanism is needed to attract them from farmland to a different place?
   - Have nets been used thus far to trap them?
8. How do you think the community would perceive the strategy of using UAS to control the Quelea populations?
9. What will be the main challenges in implementing this technology? (Cultural acceptance, technological knowledge/skill, infrastructure, etc.)
10. Are there are thoughts you would like to add?
Appendix C. Interview Protocol: UAS Subject Matter Experts

1. Can UAS be used in bird control missions?
2. If yes, how?
3. What are the major technical issues involved in the use of this technology in such missions?
4. What are non-technical barriers to this application of UAS?
5. This study is concerned with assessing the feasibility of using UAS in Quelea bird control. Do you know the Quelea bird?
   – If not explain
   – If yes, move on to 7
6. Do you think UAS may be compatible for Quelea bird control? If yes, in what ways? If not, please explain.
7. Do you know of existing UAS technology that may be suitable for this mission?
8. What obstacles may hinder its use in such a mission?
Appendix D. Survey Questions: Potential Use of Unmanned Aerial Systems for Red-Billed Quelea (quelea quelea) Control

A dissertation study by Shira Efron, Pardee RAND Graduate School, RAND Corporation

This survey addresses the need for innovative pest management practices in Red-Billed Quelea control in Kenya with a special focus on the Unmanned Aerial System (UAS). The goals of this study are twofold: first, understand the pest management challenges faced by smallholder farmers in rural Kenya; and second assess the feasibility of employing this innovative technology for such a mission. The ultimate goal is to assist farmers reduce crop damage caused by the Quelea birds.

We have designed a questionnaire to guide our discussion. Once completed, the questionnaire will be a confidential property of Pardee RAND Graduate School no information therein will be revealed to any other party. You will not be identified and no information or quotes will be attributed to you. Only a final analysis report of all questionnaires will be published.

Your participation is very important. There will be no right or wrong answers to the questions, but is important to give truthful and honest responses. We estimate that answering this survey questions will take about 30 minutes of your time and your cooperation is highly appreciated.

1. **General Information**: General information about you and your farm.

   1. **Gender**
      - Male  
      - Female

   2. **Age**
      - Less than 20  
      - 21–30  
      - 31–40  
      - 41–50  
      - 51–60  
      - Over 60

   3. **How many years have you been a farmer?** ________________

   4. **Size of your farm (in acres)** ________________

   5. **What are the main varieties of crops that you grow?** (Please mark all that apply)
      - White sorghum  
      - Red sorghum  
      - Millet  
      - Maize  
      - Wheat  
      - Rice  
      - Cotton  
      - Other

      Please specify “other”________________________________________

   6. **Are you part of a farmer group or scheme?**
      - Yes  
      - No
7. If yes, how many farmers are included in your group or scheme? ____________________

II. Scope of the Problem: This section involves questions regarding the magnitude of Quelea problem in your farm and the strategies you use to address this issue.

1. What are the main challenges you are facing in grain production? (Please mark all that apply)
   □ Drought or inconsistent rainfall □ Other weather-related phenomenon □ Red-Billed Quelea □ Other bird pests □ Non-bird pests □ Shortage of inputs □ Inputs’ prices □ Low demand □ Other
   Please specify “other” ____________________________________________

2. Have your crops ever been attacked by the Quelea bird?
   □ Yes □ No

3. If yes, how many times?
   □ Only once □ 2–3 □ 4–10 □ 11–20 □ Regularly, every (or almost every) season

4. If regularly, during which months?

5. Which crops do the Queleas prefer and cause most damage to?
   □ White sorghum □ Red sorghum □ Millet □ Maize □ Wheat □ Rice □ Other
   Please specify “other” ____________________________________________

6. Can you estimate the average crop loss per season due to the Queleas?
   □ None □ 10% □ 20% □ 30% □ 40% □ 50% □ 60% □ 70% □ 80% □ 90% □ 100%

7. What are the method/s you use to control the Quelea? (Please mark all that apply)
   □ Noise, using own voice □ Noise, using clapping □ Noise, using a tool □ Throwing stones □ Throwing stones using catapults, slingshots □ Chasing the birds running □ Have a specially-designed system with iron sheets hanging on wires □ Plant or trap crop around/within field □ Let the Queleas eat one side of field and protect the others □ Call crop protection unit □ Other
   Please specify “other” ____________________________________________

8. Who helps you control the Quelea menace?
   □ I do it on my own □ My spouse □ My spouse and children □ My children □ I hire 1 employee for the season □ I hire 2–3 employees for the season □ I hire more than 3 employees □ Other
   Please specify “other” ____________________________________________
9. Approximately how much do you spend in KES per season on birds’ pest control? (Excluding losses)


10. Has the Quelea problem changed your behavior?
☐ Yes  ☐ No

11. If yes, how? (Please mark all that apply)
☐ I shifted from white to red sorghum  ☐ Shifted to millet  ☐ Shifted to maize  ☐ Other

Please specify “other”

11. Have you noticed predatory birds targeting the Queleas?
☐ Yes  ☐ No

12. If yes, which predatory birds have you noticed?
☐ Hawks  ☐ Owls  ☐ Eagles  ☐ Other species (please list)

13. Have you ever tried eating a Quelea bird?
☐ Yes  ☐ No  ☐ Don’t know

14. Will you be open to eating Queleas?
☐ Yes  ☐ No  ☐ Maybe

If “no” or “maybe” please explain reason

II: Adoption of Innovative Pest Management Techniques: This section addresses the motivation and likelihood that you and your community will adopt new techniques to manage the Quelea birds with emphasis on UAS technology. For each question, please mark the number that most closely represents your position.

1 = strongly disagree, 2 = disagree, 3 = Not sure 4 = Agree 5 = Strongly Agree

<table>
<thead>
<tr>
<th></th>
<th>1</th>
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<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
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<td>1. I am interested in innovative techniques and tools to manage the Quelea birds.</td>
<td></td>
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<tr>
<td>2. My community is interested in innovative techniques and tools to manage the Quelea birds.</td>
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<tr>
<td>3. I am in favor of using chemicals for Quelea control.</td>
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<tr>
<td>4. I am in favor of using explosives for Quelea</td>
<td></td>
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</tr>
</tbody>
</table>
control.

5. I am in favor of trapping Queleas and eating them.

6. I am in favor of using mechanized methods of pest management for Quelea control

7. I prefer highly visible methods of pest management

8. The decision to adopt any control method depends primarily on its price

9. The decision to adopt any control method depends primarily on the difficulty of operating it

10. The decision to adopt any control method depends on the scheme and farmers around

This study is examining the feasibility of using UAVs (AKA drones) to scare off the Queleas.

12. Do you know what a drone is?

13. I am in favor of using a UAV to scare off the Queleas

14. My neighbors will be in favor of using a UAV to scare off the Queleas

15. I am interested in learning more about the potential use of UAVs to scare off the Queleas

16. I am more likely to adopt a UAV for Quelea control if other farmers in my community have already adopted it.

17. Using UAVs for Quelea–control may have negative security implications

18. Using UAVs for agriculture may have negative implications in terms of privacy

19. Using UAVs for Quelea–control or other agricultural applications may attract young people to work in agriculture

20. Some have proposed the idea of using UAVs to help locate Quelea roosts and/or spray them with chemicals. What do you think about these applications?
21. What is the biggest challenge you think you will face in adoption of UAV technology for Quelea-control?

__________________________________________________________________________

21. What other thoughts do you have about the use of UAS (UAV, AKA drone) for Quelea-control?

__________________________________________________________________________

22. What other Quelea-related stories would you like share?

__________________________________________________________________________

Thank you so much for your time in completing this survey! Asante!
Appendix E. Interview Protocol: Smallholder Crop Farmers in Kenya

1. How long have you been a farmer?
2. What is the size of your plot?
3. Describe the types of crops you are growing.
4. Have these types changed over time? If so, how?
5. If answer to #4 is yes, what were the reasons for these changes?
6. What are your main farming challenges in terms of pests?
7. Have your crops ever been subject to a Quelea Quelea attack? If yes, describe what happened and the damages that occurred and how it affected you.
8. If answer to #7 is yes, how has the attack affected your farming behavior?
9. If answer to #7 is no, do you know anyone whose crops been attacked by this bird?
10. If answer to #9 is yes, how has the attack affected their behavior?
11. Describe your pest management strategies in general, and particularly when it comes to the Quelea.
12. This study is examining the feasibility of using an unmanned aerial system (UAS; also known as drone) to scare off the Quelea Quelea.
   - Do you know what a drone is?
   - What is your view on using a drone to scare off the Quelea Quelea flocks?
   - Will you be willing to use it for other applications – collecting information on crop and soil health using remote sensing and cameras?
   - How in your opinion will the community perceive the use of such technology?
13. Are there any other thoughts you’d like to share?
Appendix F. Structure of GII and relationship to analytical framework

Table F.1 Structure of GII and Relationship to Analytical Framework

<table>
<thead>
<tr>
<th>Sub-Pillar</th>
<th>Indicator</th>
<th>Analytical Framework</th>
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<td>Political environment</td>
<td>Political stability and absence of violence/terrorism</td>
<td>Political &amp; cultural feasibility</td>
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<td>Government effectiveness</td>
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<td>Press freedom</td>
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<td>Regulator environment</td>
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<td>Cost of redundancy dismissal</td>
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## Appendix G. Modified GII Score and ranking

Table G.1 Modified GII Score and Ranking

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<thead>
<tr>
<th>Country</th>
<th>Region</th>
<th>Score</th>
<th>Input</th>
<th>Output</th>
<th>Human capital &amp; research</th>
<th>Total</th>
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<tr>
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<td>SSA</td>
<td>44.1</td>
<td>30.6</td>
<td>1.6</td>
<td>18.4</td>
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### Notes
- **Input** includes measures related to human capital and research, infrastructure, business sophistication, and knowledge and technology outputs.
- **Output** includes measures related to knowledge absorption, knowledge creation, innovation, linkages, and intangible assets.
- **Total** is the sum of input and output scores for each country.
Appendix H. Web of Science categories and their relationship to disciplinary knowledge required for UAS production

Table H.1 Web of Science Categories and Their Relationship to Disciplinary Knowledge Required for Unmanned Aerial System Production

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# Appendix K. Education Sub-Category Modification

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<td>31.261474</td>
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<tr>
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<td>Swaziland 80.86773612 2.76</td>
<td>46.34543</td>
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<tr>
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<td>Tanzania 62.28667713 9.27</td>
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<td>Zimbabwe 70.269655 7.37</td>
<td>Zimbabwe 70.27561042 0</td>
<td>42.916278</td>
</tr>
</tbody>
</table>
Appendix L. IIAG Modified Score

Table L.1 IIAG Modified Score

Country
Algeria
Angola
Benin
Botswana
Burkina Faso
Burundi
Cabo Verde
Cameroon
Côte d'Ivoire
Egypt
Ethiopia
Gambia
Ghana
Guinea
Kenya
Lesotho
Madagascar
Malawi
Mali
Mauritius
Morocco
Mozambique
Namibia
Niger
Nigeria
Rwanda
Senegal
Seychelles
South Africa
Swaziland
Tanzania
Togo
Tunisia
Uganda
Zambia
Zimbabwe

IIAG Modified Score
SUSTAINABLE
HUMAN
ECONOMIC
DEVELOPMENT
OPPORTUNITY

SAFETY & RULE
OF LAW

46.8040616
43.10603074
55.55879748
85.34085483
57.71239839
40.44744426
78.15778835
45.43950064
41.59131186
40.87676063
50.00183583
50.17641723
69.88728639
46.5359674
51.27506712
69.53333226
49.04900939
64.62720163
48.55864321
84.54630462
58.66511942
50.75295818
74.91743226
56.03853095
38.10735876
58.23563926
63.47806827
70.80097571
68.09529716
60.81058125
57.43720014
54.57678332
59.0662044
53.30549186
65.06940703
37.698407

49.85
34.64
46.96
65.90
50.97
38.54
63.13
46.19
43.55
54.21
50.41
54.24
53.63
35.88
54.39
50.39
44.07
45.94
51.79
79.71
69.09
46.84
62.21
40.94
43.29
63.39
56.67
63.58
71.91
51.63
50.47
32.79
63.29
50.06
50.95
23.51

64.13300658
44.99286664
53.94361257
70.72865878
48.30049059
47.91944985
72.33676558
57.05520648
45.75075702
55.25128042
51.19504727
62.46076709
69.38189135
45.39210123
57.67697951
50.37199647
41.78769024
51.87964588
46.80356936
75.41076834
62.27886293
44.29249494
61.20985054
46.09498551
44.26961274
68.73686103
56.52842677
79.56834985
64.97872744
56.9497194
53.25355242
53.40401217
66.14964472
57.9139938
54.66744879
50.06119191

Ranking
GOVERNANCE
SCORE

Ranking

53.59577962
40.91168101
52.15361148
73.99108669
52.32616921
42.30319157
71.20947602
49.56093753
43.63050858
50.1123147
50.53440089
55.62555199
64.30111681
42.60323595
54.4489022
56.76405105
44.96752449
54.14887052
49.05052006
79.8898256
63.34350582
47.2965317
66.11213108
47.69202829
41.88819002
63.45313583
58.89224817
71.31492242
68.32748458
56.46418769
53.71992064
46.92424911
62.8351734
53.75979881
56.89648915
37.0902024

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Country

Mauritius
Botswana
Seychelles
Cabo Verde
South Africa
Namibia
Ghana
Rwanda
Morocco
Tunisia
Senegal
Zambia
Lesotho
Swaziland
Gambia
Kenya
Malawi
Uganda
Tanzania
Algeria
Burkina Faso
Benin
Ethiopia
Egypt
Cameroon
Mali
Niger
Mozambique
Togo
Madagascar
Côte d'Ivoire
Guinea
Burundi
Nigeria
Angola
Zimbabwe

Original IIAG Ranking
Modified
Governance
Score
79.89
73.99
71.31
71.21
68.33
66.11
64.30
63.45
63.34
62.84
58.89
56.90
56.76
56.46
55.63
54.45
54.15
53.76
53.72
53.60
52.33
52.15
50.53
50.11
49.56
49.05
47.69
47.30
46.92
44.97
43.63
42.60
42.30
41.89
40.91
37.09

Ranking

1
2
3
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Country

Mauritius
Cabo Verde
Botswana
South Africa
Seychelles
Namibia
Ghana
Tunisia
Senegal
Lesotho
Rwanda
Zambia
Morocco
Tanzania
Malawi
Kenya
Benin
Uganda
Algeria
Burkina Faso
Mozambique
Gambia
Swaziland
Egypt
Mali
Niger
Ethiopia
Madagascar
Cameroon
Togo
Nigeria
Burundi
Côte d'Ivoire
Guinea
Angola
Zimbabwe

Governance
Score

81.709
76.595
76.185
73.290
73.235
70.261
68.167
65.990
64.329
62.263
60.357
59.436
58.848
58.243
57.569
57.396
56.671
56.128
54.384
53.278
52.201
51.550
51.508
51.105
49.470
49.436
48.494
48.175
47.646
46.448
45.824
45.325
44.323
43.285
40.927
38.029


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See FAA’s website http://www.faa.gov/uas/
See FAA’s website http://www.faa.gov/uas/


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This anecdote was revealed in an off-the-record conversation with experts who advise the U.S. State Department on potential manned aircraft for monitoring poaching.


As told by a Government official within Kenya’s Ministry of Transportation which overseas regulation of aircraft. For exact quote see Chapter 4. Management of the Human-Wildlife Conflict: The Red Billed Quelea Bird


A search of the terms “UAV,” “drone,” and “agriculture” together utilizing Google news over the month between June 19th to July 19th found 80 results only in U.S. news papers.

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See for example Unregulated Drones Pose a Security Threat, Says Peters (Business Day (South Africa), August 13, 2014, available at http://www.bdlive.co.za/national/2014/08/13/unregulated‐drones‐pose‐a‐security‐threat‐says‐peters


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