Development of a Livestock Management Database System towards sustainable smallholder farming systems in South Africa

by

Obvious Mapiye

Dissertation presented for the degree of
Doctor of Philosophy (Agricultural Sciences)
at
Stellenbosch University
Department of Animal Sciences, Faculty of AgriSciences

Supervisor: Dr Annelin Molotsi
Co-supervisors: Prof. Godswill Makombe
Prof. Kennedy Dzama

April 2022

Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated) that reproduction and publication thereof by Stellenbosch University will not infringe any third-party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: April 2022

Summary

The commercialisation of smallholder farmers has taken the lead on the development agenda of many developing countries. Invariably, the majority of smallholder livestock producers are less productive than commercial producers and lag in commercialisation. Apart from the multifaceted challenges that smallholder farmers face, limited access to appropriate information and extension services constrains their sustainability. Therefore, the aim of this study was to design and develop a Livestock Management Database System (LMDS) for improving the sustainability of commercially oriented smallholder cattle producers in the North West Province of South Africa. The system promotes the efficiency of delivering agricultural extension services and the upscaling of smallholder livestock production through improved access to tailored information and services. The study was guided by the pragmatic paradigm, which accommodates positivism (quantitative) and normative (qualitative) perspectives. A partially mixed sequential explanatory design with a dominant quantitative method was adopted. A structured questionnaire was administered to 101 commercially oriented beneficiaries of the Nguni cattle project in North West Province, South Africa, to collect quantitative data. Qualitative data were collected through focus group discussions (FGDs) and key informant interviews (KIIs) with farmers and extension officers, respectively. A double-bounded contingent evaluation method was used to estimate the farmers' willingness to pay (WTP) for rangeland conservation and regeneration. A binary logistic regression model was used to evaluate the determinants of farmers' WTP. The results show that most farmers (>80%) were willing to pay the initial bid price of ZAR165.00, with the estimated mean WTP being ZAR244.00 ha^{-1} $year^{-1}$ for improving rangelands. The logistic regression findings show that the farmers' WTP responses were influenced by education ($p = 0.012$), most important breed ($p = 0.039$), farming experience ($p = 0.026$), goat ownership ($p = 0.022$), ecoregion ($p = 0.079$), and income from cattle sales ($p = 0.048$). The high WTP results highlight the potential of involving the smallholder cattle farmers in implementing payment-based programs designed to improve the ecological sustainability of rangeland ecosystems and even introduce new interventions such as the LMDS. However, one of the complex challenges of driving the growth of commercially oriented smallholder farmers is ensuring that farmers understand and use new technologies. Thus, explaining their behavioural intentions before technology development is one of the most effective ways to increase adoption and identify potential design issues. Therefore, the study investigated the farmers' experiences of using ICTs and their perceptions of the usefulness of the LMDS in livestock production. Results revealed that over 75% of the farmers had smartphones and smartphone operating skills, and nearly two-thirds were using the internet to search for agricultural information. About 80% had a strong positive perception of the usefulness of the proposed LMDS towards their livestock production. FGDS and KII results also observed higher positive perceptions towards the innovation. The Chi-square statistic was used to test the association between farmers' socioeconomic characteristics and perceptions of the usefulness of the LMDS. The results show that education level, smartphone ownership, farming experience, cattle herd size and gender influenced farmers' perceptions of the LMDS. Poor mobile network connectivity (44%) and lack of digital skills (20%) were the limitations perceived to hamper the adoption of the

innovation. The deeper insights from study findings on the perceived usefulness of mobile technology can be beneficial to policymakers, researchers, and development agents and institutions when developing interventions for adoption by farmers. The LMDS development process involved a human-centred design thinking process in which development activities were based on the farmers and extension officers' needs and expectations. Development of the LMDS has reached the prototyping phase, which involves software development and validation in the actual operational environment.

Opsomming

Die kommersialisering van kleinboere het die voortou geneem op die ontwikkelingsagenda van baie ontwikkelende lande. Die meerderheid kleinveeprodusente is sonder uitsondering minder produktief as kommersiële produsente en is agter in kommersialisering. Afgesien van die veelsydige uitdagings waarmee kleinboere te doen het, beperk toegang tot toepaslike inligting en voorligtingsdienste hul volhoubaarheid. Daarom was die doel van hierdie studie om 'n Lewendehawebestuurdatabasisstelsel (LMDS) te ontwerp en te ontwikkel vir die verbetering van die volhoubaarheid van kommersieel georiënteerde kleinboerbeesprodusente in die Noordwes Provinsie van Suid-Afrika. Die stelsel bevorder die doeltreffendheid van die lewering van landbouvoorligtingsdienste en die uitbreiding van veeproduksie deur verbeterde toegang tot pasgemaakte inligting en dienste. Die studie is gelei deur die pragmatiese paradigma, wat positivisme (kwantitatiewe) en normatiewe (kwalitatiewe) perspektiewe akkommodeer. 'n Gedeeltelik gemengde opeenvolgende verklarende ontwerp met 'n dominante kwantitatiewe metode is aangeneem. ’n Gestruktureerde vraelys is aan 101 kommersieel georiënteerde begunstigdes van die Nguni-beesprojek in Noordwes Provinsie, Suid-Afrika, geadministreer om kwantitatiewe data in te samel. Kwalitatiewe data is ingesamel deur middel van fokusgroepbesprekings (FGD'e) en sleutelinformant-onderhoude (KII's) met onderskeidelik boere en voorligtingsbeamptes. ’n Dubbelbegrensde voorwaardelike evalueringsmetode is gebruik om die boere se bereidwilligheid om te betaal (WTP) vir weiveldbewaring en -herlewing te skat. ’n Binêre logistiese regressiemodel is gebruik om die determinante van boere se WTP te evalueer. Die resultate toon dat die meeste boere (>80%) bereid was om die aanvanklike bodprys van ZAR165.00 te betaal, met die geskatte gemiddelde WTP wat ZAR244.00 ha-1 jaar-1 was vir die verbetering van weiveld. Die logistiese regressiebevindinge toon dat die boere se WTP-reaksies beïnvloed is deur opvoeding (p = 0,012), belangrikste ras (p = 0,039), boerdery-ervaring (p = 0,026), bokeienaarskap (p = 0,022), ekostreek (p = 0,079), en inkomste uit beesverkope (p = 0,048). Die hoë WTP-resultate beklemtoon die potensiaal om die kleinboerbeesboere te betrek by die implementering van betalingsgebaseerde programme wat ontwerp is om die ekologiese volhoubaarheid van weiveld-ekosisteme te verbeter en selfs nuwe intervensies soos die LMDS in te stel. Een van die komplekse uitdagings om die groei van kommersieel georiënteerde kleinboere aan te dryf, is egter om te verseker dat boere nuwe tegnologieë verstaan en gebruik. Die verduideliking van hul gedragsvoornemens voor tegnologie-ontwikkeling is dus een van die doeltreffendste maniere om aanvaarding te verhoog en potensiële ontwerpkwessies te identifiseer. Daarom het die studie die boere se ervarings van die gebruik van IKT en hul persepsies van die bruikbaarheid van die LMDS in veeproduksie ondersoek. Resultate het aan die lig gebring dat meer as 75% van die boere slimfone en slimfoonbedryfsvaardighede gehad het, en byna twee derdes het die internet gebruik om na landbou-inligting te soek. Ongeveer 80% het 'n sterk positiewe persepsie gehad van die bruikbaarheid van die voorgestelde LMDS vir hul veeproduksie. FGDS- en KII-resultate het ook hoër positiewe persepsies teenoor die innovasie waargeneem. Die Chi-kwadraat-statistiek is gebruik om die verband tussen boere se sosio-ekonomiese eienskappe en persepsies van die bruikbaarheid van die LMDS te toets. Die resultate toon dat onderwysvlak, slimfooneienaarskap, boerdery-ervaring, beeskuddegrootte en geslag boere se

persepsies van die LMDS beïnvloed het. Swak mobiele netwerkkonnektiwiteit (44%) en gebrek aan digitale vaardighede (20%) was die beperkinge wat beskou word om die aanvaarding van die innovasie te belemmer. Die dieper insigte uit studiebevindinge oor die waargenome bruikbaarheid van mobiele tegnologie kan voordelig wees vir beleidmakers, navorsers en ontwikkelingsagente en -instellings wanneer intervensies vir aanvaarding deur boere ontwikkel word. Die LMDS-ontwikkelingsproses het 'n mensgesentreerde ontwerpdenkproses behels waarin ontwikkelingsaktiwiteite gebaseer is op die boere en voorligtingsbeamptes se behoeftes en verwagtinge. Ontwikkeling van die LMDS het die prototiperingsfase bereik, wat sagteware-ontwikkeling en validering in die werklike bedryfsomgewing getoets moet word.

I dedicate this dissertation to my daughter and source of inspiration, Valery Mufaro Mapiye.

Biographical sketch

Obvious Mapiye obtained a National Diploma in Agriculture from Gwebi College of the University of Zimbabwe (Harare) in 2007. In 2012, he completed his BSc degree in Agricultural Economics at the University of Zimbabwe. Obvious Mapiye worked for Fintrac Inc's ZimAied programme as an assistant to the M&E department in Harare, Zimbabwe (2013-2015). In 2015, he moved to South Africa, where he enrolled for the MSc in Sustainable Agriculture programme at Stellenbosch University (2015-2017). His MSc research focused on characterising the systemic constraints affecting the sustainability of commercially oriented cattle farmers in South Africa. The study identified the need for developing a Livestock Management Database System to help the farmers address these challenges. In 2018, he started his PhD study focusing on developing the LMDS technology for improving the sustainability of smallholder livestock farming systems in South Africa.

Research publications

Mapiye*, O., Makombe, G., Molotsi, A., Dzama K. and Mapiye, C. (2021). Towards a Revolutionized Agricultural Extension System for the Sustainability of Smallholder Livestock Production in Developing Countries: The Potential Role of ICTs. *Sustainability,* 13 (11), 5868, https://doi.org/10.3390/su13115868.

Mapiye*, O., Makombe, G., Molotsi, A., Dzama K. and Mapiye, C. (2021). Information and Communication Technologies (ICTs): The Potential for Enhancing the Dissemination of Agricultural Information and Services to Smallholder Farmers in Sub- Saharan Africa. *Information Development,* (1-21), https://doi.org/10.1177%2F02666669211064847.

Mapiye*, O., Makombe, G., Molotsi, A., Dzama K. and Mapiye, C. Commercially oriented smallholder cattle producers' willingness to pay for rangeland ecosystem services and its determinants in North-West Province, South Africa, *Ecosystems Services* (Under Review)

Mapiye*, O., Makombe, G., Molotsi, A., Dzama K. and Mapiye, C. Perceptions of the usefulness of a livestock management database system among commercially oriented smallholder cattle producers in North West Province, South Africa. *Information Technology for Development* (Under Review)

Acknowledgements

I am pleased to express my unreserved appreciation to the following persons and institutions who helped make my PhD study memorable and productive.

I am grateful to my supervisor, Dr Annelin Molotsi, for the unwavering academic support, guidance and encouragement as I developed my thesis. My special appreciation goes to my co-supervisor, Professor Godswill Makombe, for the invaluable academic mentorship, constructive instructions, and always being available to discuss and shape the way ahead. I am greatly indebted to my other co-supervisor, Professor Kennedy Dzama, for the academic grooming, exposure to various opportunities, and the sourcing of financial support to cater to my well-being during the study.

I want to acknowledge the Sustainable Agriculture group and the Department of Animal Sciences at Stellenbosch University for the research resources and administrative support. I'm grateful to Dr Rhoda Malgas for her comments and invaluable insights on "how to conduct focus group discussions". Special mention goes to Dr C. Mapiye for the academic mentorship, especially on how to write scientific research papers.

Thank you to Ms Adele Smith-Carstens and Ms Julia Harper for providing administrative support throughout the PhD study. Dr Obert Chikwanha, I acknowledge your skills, particularly in editing the document.

At the North-West Department of Agriculture Land Reform and Rural Development, I acknowledge the support from various officials in identifying the sample of commercially oriented cattle farmers used in the study. I also appreciate their support with organising FGDs and participating as Research Key Informants. These Include: Mr D Botsime, Mr A Malatsi, Mr T. Kepadisa, Mrs B. Mothupi, Mr H Sebitloane Mr K Mkwanasi, Mr T Chokue, Mr D Makabanyane, Mr Katleko, Mr T Molope and Mr A Mathe. Deepest gratitude and appreciation are extended toward all the Nguni cattle project farmers who took their valuable time to participate in the surveys and focus group discussions; without them, this research would not have been possible. I am indebted to all enumerators and facilitators who assisted with data collection in the field.

I am grateful to Dr D Motiang and Agricultural Research Council for their assistance in reaching out to the communities during our data collection exercise. The same appreciation goes to Dr E Man'ombe for organising the sample of farmers used for pre-testing the survey questionnaire. To Prof U Marume, thank you for the accommodation and warm hospitability during our research fieldwork in North West Province.

I want to recognise Mr Joubert de Wet for the long hours of intense entrepreneurial mentorship and the expertise in building the LMDS business model. Thus, it is with gratitude that I acknowledge Innovus company for providing me with the opportunity to pursue the commercialisation of LMDS technology.

My father, Mr C. Mapiye, deserves special recognition for the value of education he instilled in me and his unending support. My gratitude can never be expressed enough for my overly caring mother, Mrs A. Mapiye Mugedya, for her prayers, kind love, and moral support. To you, all my loving and supportive siblings, the Mapiye and Mwerenga families, your support has kept me going, and I am greatly indebted.

Thank you so much to my wife, Sikhumbuzo, for the unreserved love, for managing our home, our daughter, my life, and insisting that I finish this project. The things that I would have otherwise ignored. I also acknowledge all my friends and postgraduate colleagues for making my stay at Stellenbosch University so memorable. To all of these people, I am greatly indebted.

Above all, this achievement would not have come to fruition without the abounding gifts of life, peace, health and guidance under the unconditional love and mercy of our Lord God. To Thee, be all glory and praises!

Preface

This dissertation is presented as a compilation of seven chapters. Each chapter is introduced separately and is written according to the style of the journal, Information Development, to which Chapter two (b) was submitted for publication. In this regard, some repetitions between chapters may be unavoidable. Chapter two (a) was published in the journal, Sustainability. Chapter five is under review in the journal, Ecosystem Services. The quantitative section of Chapter six was submitted for publication in the journal, Information Technology for Development. The Qualitative part of Chapter six is under preparation for submission in the journal, The Qualitative Report. Sections 2.5 of Chapter two and 3.9 of Chapter three were added to improve the dissertation flow but were not in the publications.

Chapter 1 — **General introduction and project aims**

Chapter 2 (a) — **Literature review**

Towards a Revolutionised Agricultural Extension System for the Sustainability of Smallholder Livestock Production in Developing Countries: The Potential Role of ICTs

Chapter 2 (b) — **Literature review**

Information and Communication Technologies (ICTs): The Potential for Enhancing the Dissemination of Agricultural Information and Services to Smallholder Farmers in Sub-Saharan Africa

Chapter 3 — **Research methodology:** A theoretical framework

Chapter 4 — **Research results**

Commercially oriented smallholder cattle producers' willingness to pay for rangeland ecosystem services and its determinants in North-West Province, South Africa

Chapter 5 — **Research results**

Perceptions of the usefulness of LMDS in livestock production amongst commercially oriented smallholder cattle producers

Chapter 6 — **Research results**

On the development of a Livestock Management Database System Prototype and its implementation mechanisms: A Design Thinking approach

Chapter 7 — **General discussion recommendations and conclusions**

Table of Contents

List of Tables

List of Figures

List of Acronyms

AGRITEX	Department of Agricultural Technical and Extension Services
ACIAR	Australian Centre for International Agricultural Research
AGRA	Alliance for a Green Revolution in Africa
ARC	Agricultural Research Council
CKW	Community Knowledge Workers
CTA	Technical Centre for Agricultural and Rural Cooperation
CV	Contingent Valuation
DALRRD	Department of Agriculture Land Reform and Rural Development
DDCVM	Double-bounded Dichotomous Contingent Valuation Method
DT	Design Thinking
ESA	East and Southern Africa
FAO	Food and Agriculture Organization
FFS	Farmers Field School
FGD	Focus Group Discussion
FSR-E	Farming Systems Research–Extension
GFRAS	Global Forum for Rural Advisory Services
GIZ	Germany Corporation for International Cooperation-GmbH
GSMA	Global Systems for Mobile Connections
ICASA	Independent Communications Authority of South Africa
ICT	Information and Communication Technology
IDC	Industrial Development Corporation
IDRC	International Development Research Centre
ITU	International Telecommunication Union
KII	Key Informant Interviews
KLPA	Kenya Livestock Producers Association
NDA	National Department of Agriculture
LMDS	Livestock Management Database System
M&E	Monitoring and Evaluation
NALEP	National Agriculture and Livestock Extension Programme
NGO	Non-Governmental Organisation
OLR	Ordinal Logistic Regression
PES	Payment for Ecosystem Services
SDG	Sustainable Development Goals
SNRD	Sector Network Rural Development Africa
SSA	Sub-Saharan Africa
T & V	Training and Visit
USAID	United States Agency for International Development
WTP	Willingness to Pay

Chapter 1: General introduction

1.1 Background

Africa relies heavily on agriculture. Agriculture is the backbone of the continent's economy and is vital in poverty alleviation (Hopestone, 2014; Verdier-chouchane and Karagueuzian, 2016). Within Sub Saharan Africa (SSA), the agricultural industry accounts for the highest fraction of the employed population (about 65%) (AGRA, 2015). In South Africa, for example, in the 2018/19 season, it employed approximately 842 000 people and has been a direct source of food for the rural poor (AgriSA, 2019). Furthermore, agriculture continues to be ranked high because of its backward and forward linkages with the manufacturing and other sectors of the economy (DALRRD, 2018) and of major importance to the agricultural industry is the livestock sector.

In Africa, livestock is kept by 70 to 80 per cent of the poor who reside in the rural areas (Enahoro et al., 2019), who are usually smallholder farmers. Among these resource-poor smallholders, livestock is regarded as a store of wealth, source of income and food (meat and milk), and also a source of draught power and manure (organic fertilizer) (Mutami, 2015; Waters-Bayer and Bayer, 1992). Livestock is also used as collateral for credit and essential security nets against unforeseen circumstances (Mcdermott et al., 2010). In South Africa, the livestock industry is the largest and fastest-growing sub-sector of the agricultural industry and contributes approximately 50% to the total gross value of agricultural production (DALRRD, 2019). However, more contribution could be realised with the growth and sustainable transformation of the smallholder sector (IDC, 2018) because they constitute a significant proportion of livestock producers (Gwiriri et al., 2019). The smallholder sector comprises subsistence and commercially oriented farmers (IDC, 2018). Commercially oriented smallholders are also referred to as emerging smallholder farmers. Overall, smallholder livestock producers represent over 80% of the total livestock farmers in the country, owning approximately 40%, 70%, 12% of the country's cattle, goats and sheep, respectively (Gwiriri et al., 2019). However, for the past two decades, the sustainability concept is gradually becoming a high priority agenda for improving smallholder agricultural development systems (Kotze and Rose, 2015; Marandure et al., 2018; Oduniyi et al., 2020).

Promoting sustainable agriculture among smallholders entails the need to work towards achieving the three sustainability pillars, namely, economic profitability, environmental health, and social development

(Khwidzhili and Worth, 2019; Lebacq et al., 2013), which are also referred to as the three P's, respectively Profit, Planet and People (Mukherjee et al., 2016). The three pillars of sustainability are always difficult to achieve simultaneously. However, the necessity of considering sustainable agriculture in South Africa can be witnessed in recent agricultural policies, development plans and higher education training programmes which demonstrate the solicitude of policy makers and various industry stakeholders towards the need for sustainability in agriculture (DALRRD, 2014). This is consistent with (Khwidzhili and Worth, 2019), who present the philosophical argument that promoting sustainable agricultural activities should be a goal of public agricultural extension in South Africa. Of importance in developing public extension systems and the mainstreaming of sustainable agriculture, especially in smallholder farming systems, is the integration and adoption of information and communication technologies (ICTs) into farming.

Already the ICT revolution has radically transformed how people work, access information, and interact in the agricultural industry (FAO, 2018; Kenny and Regan, 2021; Trendov et al., 2019). As a result of the rapid penetration and propagation of mobile phones and the internet, Africa is more interconnected than ever (Trendov et al., 2019; World Bank, 2016). In 2018, SSA registered more than 455 million unique mobile subscribers (GSMA, 2019). Currently, the region has a mobile subscriber penetration rate of 45% and a mobile internet adoption rate of 24% (GSMA, 2019). In South Africa, at present, there are more than 90 million mobile connections (Statista, 2020) of the total mobile connections; more than 20 million are smartphone-based.

Despite the SSA region still lagging in network connectivity, the 5G era has begun and is gaining momentum. Vodacom and MTN launched the first major 5G networks in 2020 and have started offering 5G mobile and fixed wireless access (FWA) services to many locations across South Africa (GSMA, 2020). Elsewhere in SSA, key trials on the adoption of 5G have been conducted in Gabon, Kenya, Nigeria, and Uganda. On the other hand, mobile internet adoption for SSA is gradually increasing (26% at the end of 2019) (GSMA, 2019). Accessing the internet unlocks the possibility of driving smallholder agricultural activities through ICT-based strategies. The increasing adoption of smartphones is key in advancing internet use, especially among smallholder farmers in rural areas (Qiang et al., 2012; Wyrzykowski, 2020). This is because much of the online activities take place on mobile phones. This revolution of ICTs leads to the development of ICT-based technologies with the potential to support farmers, especially smallholders, with access to information, markets and other agri-services (Costopoulou et al., 2016; ITU, 2014; Smidt, 2021;

World Bank, 2017). There are numerous examples of mobile-based technologies developed and deployed to support the transformation of subsistence smallholder farmers and improve the delivery of agricultural extension services in developing countries (Aker, 2011; Kassem et al., 2021; Khan et al., 2019). According to Tsan et al. (2019), more than 33 million smallholder farmers and pastoralists across Africa are registered users of digital agricultural solutions.

Generally, there are indications that ICT-based interventions can facilitate access to valuable agricultural information, inputs and services in commercially oriented smallholder farming systems where production skills and resources are scarce (Aker, 2011; Khan et al., 2019). According to Ogutu et al. (2014), the technologies reduce the tremendous communication asymmetry between farmers and the knowledge about new agricultural innovations. For instance, they can present opportunities where farmers could share innovations and skills which can be used to drive change and sustainably grow farming systems (Daum et al., 2018; FAO, 2017). Another advantage to using ICTs, including mobile phones and the internet, is that agricultural extension staff can receive feedback directly from farmers (Baruah and Mohan, 2018; Ogutu et al., 2014) and use it to provide tailored solutions in real-time. Thus, mobile technologies and the internet are expected to drive a significant turnaround in agriculture (Batchelor et al., 2014; Bizikova et al., 2020), for example, through the mainstreaming of sustainable agriculture farming practices among farmers.

Despite the significant growth in the availability of these tools and initiatives, accessibility and usage have remained low within smallholder farming systems, especially amongst women (Edwards et al., 2014; Henze and Ulrichs, 2016; Trendov et al., 2019). Thus, many factors hamper access and efficient utilisation of digital technologies among smallholder farmers. In general, some of these factors include low digital and internet skills, especially among old farmers (Henze and Ulrichs, 2016), high costs of gadgets and signal connections (Misaki et al., 2018; Tsan et al., 2019), lack of supportive infrastructure (AGRA, 2015; World Bank, 2017), lack of innovative institutions to support farmers (Hazell et al., 2007) as well as some cultural attitudes and norms for instance that discriminates against women (FAO, 2018). However, the adoption and optimal use of ICTs in Africa's smallholder agriculture require addressing such concerns and deeper issues related to development processes, involvement of potential users and understanding their needs, behaviour, perceptions, attitudes and willingness to pay (WTP) before technology development (Alomia-Hinojosa et al., 2018; Massresha et al., 2021; Misaki et al., 2018).

1.2 Problem statement

Resource-poor smallholder livestock farmers in developing and emerging economies face sustainability challenges and continue to lag in the transition to commercial farming (FAO, 2017; Gwiriri et al., 2019; Hemming et al., 2018; Ogbeide and Ele, 2015). Invariably, empirical research suggests that sustainability lags due to various production, marketing, ecological and institutional challenges like poor cattle breeding management, parasites and diseases, low market prices, poor market reliability, lack of finance and poor access to extension services (Khapayi and Celliers, 2015; Mapiye et al., 2018). As these are substantial day-to-day constraints, the need to provide farmers with timely and tailored information and services that address their constraints to enable them to become sustainable cannot be overemphasised (Henze and Ulrichs, 2016; Trendov et al., 2019).

Sustainable agriculture is also perceived to be a knowledge-intensive concept (Batchelor et al., 2014; FAO, 2017), but smallholder farmers lack appropriate skills and information to match this demand to achieve sustainability. Many studies (Amer et al., 2018; Brhane et al., 2017; Mapiye et al., 2019) clearly describe how lack of information constraints the farmers' decision-making process. Mbanda-Obura et al., (2017) state that this situation instigates sub-optimal choices and consequently weakens the ability of farmers to address challenges and optimally respond to commercialisation opportunities. In South Africa, the public extension system is the primary source of information for smallholders (Koch and Terblanché, 2013; Mapiye et al., 2019) and is expected to address this information gap, but there are widespread concerns that it is inefficient in driving the sustainability of farmers (Akpalu, 2013; Aliber and Hall, 2012; DALRRD, 2014; Davis and Terblanche, 2016). This is because the system is heavily under-resourced, over-stretched (high farmer-to-extension worker ratio), lacks accountability and is beset by 'silo' or 'principal-agent' and bureaucratic processes that render it ineffective (FAO, 2017; Liebenberg, 2015; Raidimi and Kabiti, 2019). Public extension systems also do not effectively hasten farmer-to-farmer skills exchange and do not create the space for farmers to feedback into the system or link with local researchers (Tsan et al. 2019). In South Africa, the need for strategies that effectively add value to the public extension system has been reported for too long without effective actions (Brhane et al., 2017).

A review of the literature suggests the potential of using ICT-based strategies to revitalise extension delivery to farmers. This is also recommended in the draft extension policy of 2014 (DALRRD, 2014), however since this recommendation was made, no efforts have been made to operationalise the recommendation (FAO, 2017; Mapiye et al., 2019; Nakasone et al., 2013). Hazell et al. (2007) argued that this is worsened by the lack of innovative institutions that support smallholder farmers. There is limited research on the development process of ICT-based strategies for extension support and their impact on farmer production. There is also limited research on how smallholder users perceive the ICT-based solutions and their WTP for accessing the solutions. Many mobile and web-based innovations have been developed and deployed, mainly in East and Central Africa, to support smallholder farmers (Costopoulou et al., 2016; Tsan et al., 2019; World Bank, 2017). However, there is a lack of empirical evidence to support their impact on farmer productivity and sustainability due to the lack of baseline conditions and limited adoption and scalability (Tsan et al., 2019). Most initiatives fail to operate on a sustainable business model because they exclude farmers in their development process, and therefore, the farmers lack trust (Misaki et al., 2018) and are not prepared to pay to access them (Costopoulou et al., 2016). Farmers' WTP for new technologies is complex to understand and cannot be assumed. The WTP behaviour of commercially oriented smallholder farmers towards new interventions for supporting their farming systems is not well explored in countries like South Africa. The developers are usually more focused on building the actual technologies (techno-centric) and not on the unique needs and preferences of farmers (farmer-centric development) (Batchelor et al., 2014), which negatively influences the adoption and overall efficiency of the innovations.

This study proposes to design and develop an LMDS innovation that can be optimally used to improve the efficiency of the South African public extension system and generate demonstrable sustainability impacts for smallholder livestock producers while addressing some of the issues that have constrained the realisation of the proposed impacts of other ICT-based solutions.

1.3 Justification

The sustainability of smallholder livestock production in South Africa is positioned at the interface of various environmental, economic, social and political issues (FAO, 2017; Khapayi and Celliers, 2015; Mapiye et al., 2018). Effective agricultural extension remains a key potential solution to these challenges and in realising the envisioned long-term sustainability of farmers (Akpalu, 2013; DALRRD, 2014;

Khwidzhili and Worth, 2019). Given the chronic inefficiencies associated with South Africa's public extension (Davis and Terblanche, 2016; Duvel, 2000), the agricultural extension draft policy of 2014 recommends the need to drive extension revolution using ICT-based strategies (DALRRD, 2014). In this sense, the submission of that policy framework underscores part of the rationale behind the current study.

The development of the LMDS platform will present an opportunity to nudge the agricultural extension system towards becoming a more participatory and farmer-centric system. It will be designed as an easy-to-follow mobile phone and web-based application suite that farmers, extension officers, researchers, and other agri-value chain stakeholders can access using mobile phones and computers. The system is expected to provide a wide range of support mechanisms for the targeted users. Thus, the LMDS will renew the extension system and potentially revolutionise it by promoting cost-effective extension-farmer interactions with feedback loops that do not exist in other similar interventions. Thus, extension officers can reach many farmers without travelling by regularly and timely disseminating information to farmers through the platform. Farmers will have the opportunity to share skills and experiences amongst themselves and to work collectively to assist each other rather than waiting for solutions from the government all the time. Extension officers and farmers can also link with local researchers to articulate their unique research needs for the investigation and subsequent development of more localised solutions.

Moreover, the innovation's database will allow farmers to start recording farm activities for their future consultation and or for the Department of Agriculture Land Reform and Rural Development (DALRRD) to make strategic decisions. The database will also facilitate the development of a compendium of indigenous technical knowledge (ITK) obtained by tapping into farmer skills sharing interactions. Indigenous technical knowledge can then be used for future reference by other farmers and extension officers, while researchers might be interested in testing and refining it. Therefore, this process of developing the LMDS provides valuable insights to policymakers, innovators, and researchers when devising strategies to revitalise agricultural extension systems or developing interventions to promote the sustainability of smallholder farmers.

1.4 Aim and Objectives

The study aims to develop a Livestock Management Database System to improve agricultural extension efficiency and drive the growth and sustainability of commercially oriented smallholder livestock producers in South Africa.

The specific objectives of the study are to:

1. To demonstrate theoretically the potential of ICTs in revolutionising agricultural extension approaches and addressing constraints that limit the sustainability of smallholder farmers in developing countries;
2. To elicit the commercially oriented smallholder cattle farmers' WTP for improving rangelands and its influencing factors in North-West Province, South Africa.
3. To investigate the perceptions of the usefulness of LMDS in livestock production amongst commercially oriented smallholder cattle producers
4. To design and create the LMDS application and document the mechanisms and processes through which it scales and contributes to the sustainability of farmers.

1.5 Research questions

The following specific research equations will guide the study;

1. What are the common agricultural extension approaches used in Africa and South and East Asia and their limitations? What potential do ICTs have to revolutionise the extension approaches and address constraints limiting smallholder farmers' sustainability in developing countries?
2. What is the WTP for improving rangelands by commercially oriented smallholder farmers, and what factors influence their WTP decisions?
3. What are the perceptions of the usefulness of LMDS in livestock production amongst commercially oriented smallholder cattle producers?
4. How can the LMDS prototype innovation be effectively developed, and what mechanisms and processes should be in place for scalability and improving the sustainability of farmers?

1.6. Significance

The study findings will add to the body of knowledge and assist in improving awareness and understanding of the current experiences and perceptions of smallholder farmers and extension on the usefulness of ICT-based technologies in agricultural extension delivery and livestock management. Development of the LMDS prototype will present an opportunity to transform the South African agricultural extension model (T&V) from being largely supply-centred to demand-centred and participatory. Improving the extension system's efficiency contributes to the sustainability and productivity of smallholder farming and its contribution to food security for the country and the region. The ability of farmers to share information and communicate with extension and researchers without having to travel (using mobiles and the internet) will not only save their time and costs but is ideal in situations like the COVID-19 pandemic where for some months the country was placed on lockdown and people were restricted from travelling. The study will also provide baseline information and the Monitoring and Evaluation (M&E) logical framework matrix model to support further improvements on the initiative and in assessing its impacts.

1.7 References

AGRA (2015) *Africa Agriculture Status Report 2015. Youth in Agriculture in Sub-Saharan Africa*. Alliance for a Green Revolution in Africa (AGRA), Nairobi. Available at: http://www.agra.org/media-centre/news/africa-agriculture-status-report--2015-/.

AgriSA (2019) *Economic and Trade: Economic review 2019*. Agriculture South Africa (AgriSA), Pretoria, South Africa.

Aker JC (2011) Dial " A " for Agriculture: A Review of Information Communication Technologies for Agriclutural Extension in Developing Countries. *Agricultural Economics* 42(269): 631–647. DOI: https://doi.org/10.1111/j.1574-0862.2011.00545.x.

Akpalu DA (2013) Agriculture Extension Services Delivery in a Semi-Arid Rural area in South Africa: The Case Study of Thorndale in the Limpopo Province. *African Journal of Food, Agriculture, Nutrition and Development* 13(4). Available at: https://www.ajol.info/index.php/ajfand/article/view/94600.

Aliber M and Hall R (2012) Support for Smallholder Farmers in South Africa: Challenges of Scale and Strategy. *Development Southern Africa* 29(4): 548–562. DOI: 10.1080/0376835X.2012.715441.

Alomia-Hinojosa V, Speelman EN, Thapa A, et al. (2018) Exploring farmer perceptions of agricultural innovations for maize-legume intensification in the mid-hills region of Nepal. *International Journal of Agricultural Sustainability* 16(1): 74–93. DOI: 10.1080/14735903.2018.1423723.

Amer J, Odero D and Kwake A (2018) Towards Improving Agricultural Marketing Information Systems for Smallholder Farmers: A Tharaka Nithi Case. *Journal of Agriculture and Sustainability* 11(2): 99–128.

Baruah A and Mohan M (2018) The Farmers ' View Towards the Use of Information and Communication Technology in Agriculture : A Study Among Farmers in the Ner (North- Eastern Region) of India. *Journal of Emerging Technologies and Innovative Research (JETIR)* 5(11): 17–23.

Batchelor S, Scott N, Manfre C, et al. (2014) Is there a role for mobiles to support sustainable agriculture in Africa? In: *ICT for Sustainability 2014, ICT4S 2014*, Stockholm, 2014, pp. 272–280. DOI: 10.2991/ict4s-14.2014.33.

Bizikova L, Brewin S, Bridle R, et al. (2020) *The Sustainable Agriculture Transition :Technology options for low- and middle-income countries*. Winnipeg. Available at: https://www.iisd.org/system/files/2020-08/sustainable-agriculture-transition-technology.pdf.

Brhane G, Mammo Y and Negusse G (2017) Sources of information and information seeking behavior of smallholder farmers of Tanqa Abergelle Wereda, central zone of Tigray, Ethiopia. *Journal of Agricultural Extension and Rural Development* 9(4): 47–52. DOI: 10.5897/jaerd2016.0850.

Costopoulou C, Ntaliani M and Karetsos S (2016) Studying Mobile Apps for Agriculture. *IOSR Journal of Mobile Computing & Application* 3(6): 1–6. DOI: 10.9790/0050-03064449.

DALRRD (2014) *National Policy on Eextension and Advisory Services*. Department of Agriculture Land Reform and Rural Development (DALRRD), Pretoria, South Africa.

DALRRD (2018) *Economic Review of the South African Agriculture 2017/2018. Statistics and Economic Analysis*. Department of Agriculture Land Reform and Rural Development (DALRRD), Pretoria, South Africa.

DALRRD (2019) *Profile of the South African Beef Market Value Chain*. Department of Agriculture Land Reform and Rural Development (DALRRD), Pretoria, South Africa.

Daum T, Buchwald H, Gerlicher A, et al. (2018) Smartphone apps as a new method to collect data on smallholder farming systems in the digital age : A case study from Zambia. *Computers and Electronics in Agriculture* 153. Elsevier: 144–150. DOI: 10.1016/j.compag.2018.08.017.

Davis KE and Terblanche SE (2016) Challenges Facing the Agricultural Extension Landscape in South Africa, Quo Vadis? *S. Afr. J. Agric. Ext.* 44(2): 231–247. DOI: http://dx.doi.org/10.17159/2413-3221/2016/v44n2a428.

Duvel GH (2000) Towards an Appropriate Extension Approach for Agricultural and Rural Development in South Africa. *South African Journal of Agricultural Extension* 29(1): 10–23.

Edwards B, Tassi R, Tse L, et al. (2014) *mAgri Design Toolkit: User-centered design for mobile agriculture*. United Kingdom. Available at: https://www.comminit.com/ict-4-development/content/magri-design-toolkit-user-centered-design-mobile-agriculture.

Enahoro D, Mason-D'Croz D, Mul M, et al. (2019) Supporting sustainable expansion of livestock production in South Asia and Sub-Saharan Africa: Scenario analysis of investment options. *Global Food Security* 20(January). Elsevier B.V.: 114–121. DOI: 10.1016/j.gfs.2019.01.001.

FAO (2017) *Information and Communication Technology (ICT) in Agriculture: A Report to the G20 Agricultural Deputies*. Rome: Food and Agriculture Organisation (FAO). Available at: www.fao.org/publications.

FAO (2018) *Gender and ICTs: Mainstreaming Gender in the Use of Information and Communication Technologies (ICTs) For Agriculture and Rural Development*. Rome: Food and Agriculture Organisation (FAO). Available at: https://www.fao.org/documents/card/en/c/I8670EN/.

GSMA (2019) *Mobile Internet Connectivity 2019: Sub-Saharan Africa Factsheet*. Global Systems for Mobile Connections (GSMA), Nairobi. Available at: www.mobileconnectivityindex.com.

GSMA (2020) *The mobile Economy: Sub-Saharan Africa 2020*. Global Systems for Mobile Connections (GSMA), United Kingdom. Available at: https://www.gsma.com/mobileeconomy/wp-content/uploads/2020/09/GSMA_MobileEconomy2020_SSA_Eng.pdf.

Gwiriri LC, Bennett J, Mapiye C, et al. (2019) Constraints to the sustainability of a 'systematised' approach to livestock marketing amongst smallholder cattle producers in South Africa. *International Journal of Agricultural Sustainability* 17(2). Taylor & Francis: 189–204. DOI: 10.1080/14735903.2019.1591658.

Hazell P, Poulton C, Wiggins S, et al. (2007) *The Future of Small Farms for Poverty Reduction and Growth*. *The Future of Small Farms for Poverty Reduction and Growth*. 42. Washington DC. DOI: 10.2499/97808962976472020vp42.

Hemming DJ, Chirwa EW, Ruffhead HJ, et al. (2018) Agricultural Input Subsidies for Improving Productivity, Farm Income , Consumer Welfare and Wider Growth in Low- and Middle-Income Countries A Systematic Review. *Agriculture* (41): 1–139. DOI: https://doi.org/10.23846/SR51062.

Henze J and Ulrichs C (2016) The potential and limitations of mobile-learning and other services in the agriculture sector of Kenya using phone applications. In Proceedings of the 12th European International Farming Systems Association (IFSA) Symposium, Social and Technological Trans. In: Shropshire, UK, 2016, pp. 1–11. International Farming Systems Association (IFSA). Available at: https://www.harper-adams.ac.uk/events/ifsa/papers/2/2.5 Henze.pdf.

Hopestone KC (2014) The Role of ICTs in Agricultural Production in Africa. *Journal of Development and Agricultural Economics* 6(7): 279–289. DOI: 10.5897/jdae2013.0517.

IDC (2018) *A study on the potential product development for the commercialization and value add to beef products*. Pretoria, South Africa.

ITU (2014) *Digital Opportunities: Innovative ICT Solutions for Youth Employment*. International Telecommunication

Union (ITU), Geneva. Available at: http://girlsinict.org/sites/default/files/pages/youthreport_2014.pdf.

Kassem HS, Alotaibi BA, Ghoneim YA, et al. (2021) Mobile-based advisory services for sustainable agriculture: Assessing farmers' information behavior. *Information Development* 37(3): 483–495. DOI: 10.1177/0266666920967979.

Kenny U and Regan Á (2021) Co-designing a smartphone app for and with farmers: Empathising with end-users' values and needs. *Journal of Rural Studies* 82(January): 148–160. DOI: 10.1016/j.jrurstud.2020.12.009.

Khan NA, Qijie G, Ali S, et al. (2019) Farmers' use of mobile phone for accessing agricultural information in Pakistan: A case of Punjab province. *Ciencia Rural* 49(10). Universidade Federal de Santa Maria. DOI: 10.1590/0103-8478cr20181016.

Khapayi M and Celliers PR (2015) Issues and constraints for emerging farmers in the Eastern Cape Province, South Africa. *African Journal of Agricultural Research* 10(41): 3860–3869. DOI: 10.5897/ajar2015.9956.

Khwidzhili RH and Worth S (2019) Evaluation of the South Africa's Public Agricultural Extension in the Context of Sustainable Agriculture. *South African Journal of Agricultural Extension* 47(1): 20–35. DOI: http://dx.doi.org/10.17159/2413-3221/2019/v47n1a486.

Koch B and Terblanché S (2013) An Overview of Agricultural Extension in South Africa. *South African Journal of Agricultural Extension* 41(1): 107–117.

Kotze I and Rose M (2015) *Farming Facts and Futures: Reconnecting South Africa's Food Systems to its Ecosystems*. Cape Town. Available at: https://www.wwf.org.za/food/?13821/farming-facts.

Lebacq T, Baret P V. and Stilmant D (2013) Sustainability indicators for livestock farming. A review. *Agronomy for Sustainable Development* 33(2): 311–327. DOI: 10.1007/s13593-012-0121-x.

Liebenberg F (2015) *Agricultural Advisory Services in South Africa*. Pretoria.

Mapiye O, Makombe G, Mapiye C, et al. (2018) Limitations and prospects of improving beef cattle production in the smallholder sector: a case of Limpopo Province, South Africa. *Tropical Animal Health and Production* 50(7). Springer Netherlands: 1711–1725. DOI: 10.1007/s11250-018-1632-5.

Mapiye O, Makombe G, Mapiye C, et al. (2019) Management information sources and communication strategies for commercially oriented smallholder beef cattle producers in Limpopo province, South Africa. *Outlook on Agriculture* 49(1): 50–56. DOI: 10.1177/0030727019860273.

Marandure T, Makombe G, Dzama K, et al. (2018) Towards a system-specific framework for the sustainability evaluation of low-input ruminant meat production systems in developing countries. *Ecological Indicators* 85. Elsevier: 1081–1091. DOI: 10.1016/j.ecolind.2017.11.015.

Massresha SE, Lema TZ, Neway MM, et al. (2021) Perception and determinants of agricultural technology adoption in North Shoa Zone, Amhara Regional State, Ethiopia. *Cogent Economics and Finance* 9(1). Cogent. DOI: 10.1080/23322039.2021.1956774.

Mbanda-Obura SA, Tabu IM, Amudavi DM, et al. (2017) Determinants of choice of agricultural information sources and pathways among sorghum farmers in Ndhiwa sub-county, western Kenya. *International Journal of Agricultural Extension* 5(1): 39–49. Available at: https://escijournals.net/index.php/IJAE/article/view/2012.

Mcdermott JJ, Staal SJ, Herrero M, et al. (2010) Sustaining Intensification of Smallholder Livestock Systems in the Tropics ☆. *Livestock Science* 130. Elsevier B.V.: 95–109. DOI: 10.1016/j.livsci.2010.02.014.

Misaki E, Apiola M, Gaiani S, et al. (2018) Challenges facing sub-Saharan small-scale farmers in accessing farming information through mobile phones: A systematic literature review. *Electronic Journal of Information Systems in Developing Countries* 84(4): 1–12. DOI: 10.1002/isd2.12034.

Mukherjee A, Kamarulzaman NH, Vijayan G, et al. (2016) *Sustainability: A Comprehensive Literature* (B Christiansened.). Hershey PA: IGI Global. DOI: 10.4018/978-1-4666-9639-6.ch015.

Mutami C (2015) Smallholder Agriculture Production in Zimbabwe: A Survey. *The Journal of Sustainable Development* 13(2): 140–157. DOI: 10.7916/D8F47NV5.

Nakasone E, Torero M and Minten B (2013) The Power of Information: The ICT Revolution in Agricultural Development. *Annual Review of Resource Economics* 6(1): 533–550. DOI: 10.1146/annurev-resource-100913-012714.

Oduniyi OS, Rubhara TT and Antwi MA (2020) Sustainability of Livestock Farming in South Africa. Outlook on

Production Constraints, Climate-related Events, and Upshot on Adaptive Adapacity. *Sustainability* 12(7). DOI: 10.3390/su12072582.

Ogbeide OA and Ele I (2015) Smallholder Farmers and Mobile Phone Technology in Sub-Sahara Agriculture. *Mayfair Journal of Information and Technology Management in Agriculture (MJITMA)* 1(1): 1–19.

Ogutu SO, Okello, Julius J and Otieno DJ (2014) Impact of Information and Communication Technology-Based Market Information Services on Smallholder Farm Input Use and Productivity : The Case of Kenya. *World Development* 64. Elsevier Ltd: 311–321. DOI: 10.1016/j.worlddev.2014.06.011.

Qiang CZ, Kuek SC, Dymond A, et al. (2012) *Mobile Applications for Agriculture and Rural Development*. Washington DC.

Raidimi EM and Kabiti HM (2019) A Review of The Role of Agricultural Extension and Training in Achieving Sustainable Food Security: A Case of South Africa. *South African Journal of Agricultural Extension* 47(3): 120–130. DOI: http://dx.doi.org/10.17159/2413-3221/2019/v47n3a520.

Smidt HJ (2021) Factors affecting digital technology adoption by small-scale farmers in agriculture value chains (AVCs) in South Africa. *Information Technology for Development*. Taylor & Francis: 1–27. DOI: 10.1080/02681102.2021.1975256.

Statista (2020) Telecommunications equipment - statistics & facts. Available at: https://www.statista.com/topics/2844/telecommunications-equipment/ (accessed 28 March 2021).

Trendov N, Varas S and Zeng M (2019) *Digital technologies in Agriculture and Rural Areas*. Rome. DOI: 10.4324/9780429507533-13.

Tsan M, Totapally S, Hailu M, et al. (2019) *The Digitalisation of African Agriculture: Report 218-219*. Wageningen.

Verdier-chouchane A and Karagueuzian C (2016) Moving towards a green productive agriculture in Africa: The role of ICTs. *Africa Economic Brief* 7(7): 1–12.

Waters-Bayer A and Bayer W (1992) The role of livestock in the rural economy. *Nomadic Peoples* 31: 3–18. Available at: https://www.jstor.org/stable/43123370.

World Bank (2016) *World Development Report 2016: Digital Dividends*. Washington DC: The World Bank. DOI: doi:10.1596/978-1-4648-0671-1.

World Bank (2017) *ICT in Agriculture: Connecting Smallholders to Knowledge, Networks, and Institutions*. Updated Ed. Washington DC: The World Bank.

Wyrzykowski R (2020) *Mobile connectivity in Sub-Saharan Africa: 4G and 3G connections overtake 2G for the first time*. United Kingdom. Available at: https://openknowledge.worldbank.org/handle/10986/19032 License: CC BY 3.0 IGO.”.

Chapter 2 (a): Towards a Revolutionized Agricultural Extension System for the Sustainability of Smallholder Livestock Production in Developing Countries: The Potential Role of ICTs

Abstract

The creation of commercialization opportunities for smallholder farmers has taken primacy on the development agenda of many developing countries. Invariably, most of the smallholders are less productive than commercial farmers and continue to lag in commercialization. Apart from the various multifaceted challenges which smallholder farmers face, limited access to extension services constrains their sustainability. Across Africa and Asia, public extension is envisioned as a fundamental part of transforming smallholder farmers because it is their major source of agricultural information. Agricultural extension continues to be deployed using different approaches which are evolving. For many decades, various authors have reported the importance of the approaches that effectively revitalize extension systems and have attempted to fit them into various typologies. However, there is a widespread concern over the inefficiency of these extension approaches in driving the sustainability of the smallholder farming agenda. Further, most of the approaches that attempted to revolutionize extension have been developed and brought into the field in rapid succession, but with little or no impact at the farmer level. This study chapter explores the theory and application of agricultural extension approaches and argues the potential of transforming them using digital technologies. The adoption of ICTs such as mobile phones and the internet, which are envisaged to revolutionize existing extension systems and contribute towards the sustainability of smallholder farming systems is recommended.

2.1 Introduction

In the past 25 years, the creation of commercialization opportunities for smallholder livestock producers has taken primacy on the development agenda of many developing countries. However, most of the smallholder producers are invariably less productive than commercial farmers and continue to lag in commercialization (Hemming et al., 2018; Ogbeide and Ele, 2015). Across Africa and Asia, many governments, together with the private sector and non-governmental institutions, have extended different forms of support to reduce the lag in commercialization by smallholders and leapfrog their transformation to commercial farming (Aliber and Hall, 2012; Hemming et al., 2018).

Countries such as South Africa have attempted to support smallholder livestock farming through measures such as the provision of inputs, land, production, and marketing infrastructure, unfettering of agricultural markets, and improvement of financial access (Liebenberg, 2015). While the deployment of such measures might be the necessary conditions for bolstering the sustainability of farmers, it is posited that, unless agricultural extension approaches are radically transformed, the intent of these strategies is most likely not to be realized (Aliber and Hall, 2012; Deichmann et al., 2016; Terblanche, 2008). These attempts are generally regarded as costly and ineffective (Aliber and Hall, 2012) and lacking extension-based follow-up support. Apart from that, Anandajayasekeram et al. (2007) noted that many governments had decimated their budgetary support towards the agricultural sector, making it even more difficult for it to deliver agricultural extension services. Smallholder farmers' uneven access to agricultural extension services due to limited public extension support is, therefore, one of the key factors hampering their potential to commercialize (Henze and Ulrichs, 2016; Trendov et al., 2019). Inadequate access to extension services and appropriate agricultural information further reduces the ability of farmers to address everyday challenges and optimize the path to commercialization (Aliber and Hall, 2012; Danso-Abbeam et al., 2018; Gwala et al., 2016; Mapiye et al., 2019).

The public extension system is the largest and most common source of information for smallholder livestock farmers in developing countries (Eicher, 2007; Raidimi and Kabiti, 2019). It is one of the major undertakings of the government, with the Ministries of Agriculture having a de facto monopoly over the provision of extension and advisory services (Baig and Aldosari, 2013; Meena and Singh, 2013; Millar, 2009). However, there is a widespread concern that the public extension system is underperforming and has failed to effectively push the smallholder commercialization agenda (Cook et al., 2021; FAO, 2017; Gwala et al., 2016). This has driven the need for research and innovation strategies that promote the development of resilient and farmer-driven extension systems. To improve efficiency, most extension systems across Africa and Asia have attempted to move from supply-driven to pluralistic and demand-driven but with minor success (Davis and Terblanche, 2016; Duvel, 2000; Meena and Singh, 2013).

A review of the literature suggests the potential of linking extension systems with ICT-based strategies to promote and hasten farmer–farmer interactions and the ability of farmers to effectively communicate with extension and researchers (feedbacking) (Costopoulou et al., 2016; FAO, 2017; Mapiye et al., 2019; Marwa et al., 2020; Ogbeide and Ele, 2015). However, as noted by Hazell et al. (2007), most developing countries lack innovative institutions to support extension delivery to farmers and the development of smallholder farming. Therefore, the adoption and use of ICTs such as web-based and mobile applications (mobile Apps) present unprecedented opportunities for transforming smallholder farming (Meena and Singh, 2013; Qiang et al., 2012; Trendov et al., 2019). Already, some initiatives have been developed across Africa and Asia to support the delivery of extension services to farmers (Costopoulou et al., 2016; Tsan et al., 2019). In Africa, most of the initiatives started in East Africa, where over 60% of all registered smallholder farmers currently using digital technologies are based. This shows an enormous gap for the Southern African region. Therefore, the continued development and implementation of innovative strategies in revolutionizing public extension services is essential (Wesley and Faminow, 2014). This review discusses the main limitations of improving the sustainability of smallholder livestock production in developing countries and the role of agricultural extension. It identifies and characterizes agricultural extension approaches used in Africa and South and East Asia. The review also explores the theoretical and practical application of the extension approaches in various countries, their respective implementation objectives, assumptions, and their advantages and limitations. The potential for using ICTs in revolutionizing public extension services delivery towards sustainable smallholder farming systems is highlighted.

2.2 Review methodology

All eligible academic articles used in the review were identified by systematically searching the major electronic databases such as AGRICOLA, Google Scholar, Science Direct, SciELO, SCOPUS, and SpringerLink. Initially, a broad Boolean search string ‘smallholder farming’ AND ‘livestock’ AND ‘agricultural extension’ AND ‘developing countries’ was used. In this review, developing countries refer to the less developed and emerging economies in Africa and South and East Asia. The search was then narrowed to focus on specific extension approaches used by some countries in these regions. For example, a combination of the terms “Training and Visit”, “Extension”, and “Approach” was used to search for articles about the Training and Visit extension approach. The main search engines provided links for free to access full-text articles, and if not found, research websites such as ResearchGate, which offer an option of direct full-text request from authors, were utilized. The Google Search engine was used to retrieve research articles and reports that may have been dropped from the first search. The first method involved searching reference lists of identified review articles, and the second method involved performing citation tracking in which all the articles that cite each of the included articles were tracked. Literature published between the periods 1980 and 2021 were selected in the search. The search was conducted in 11-year periods (1980–1990; 1991–2001; 2002–2012; 2013–2021). The proportions of articles obtained for each time period were 5%, 8%, 26%, and 61%, respectively

2.3 Limitations of Improving the Sustainability of Smallholder Livestock Production and the Role of Agricultural Extension in Developing Countries

Smallholder livestock farming in many developing countries is challenged by several factors. These can be broadly classified into ecological, economic, social, and institutional challenges. Some of these major challenges being faced by the farmers include severe incidences of droughts (Kohler, 2016; Udmale et al., 2014), water and feed shortages, poor breeding management practices, and limited animal welfare and health skills (Oduniyi et al., 2020). Apart from that, smallholders' lack of access to formal, high-value output markets is one challenge limiting their environment for economic growth and development (Mcdermott et al., 2010; Thamaga-Chitja and Morojele, 2014). Thus, smallholder farmers are forced to compete for market share with already established commercial producers, where they are often dislodged due to a lack of competitive advantage. This is also due to a lack of precise market information and knowledge about how the markets function (Thamaga-Chitja and Morojele, 2014), and market unreliability incidences such as inconsistent pricing and inappropriate (possibly unfair) grading and classification of produce (Chingala et al., 2017; Mcdermott et al., 2010). Furthermore, a large proportion of smallholder farmers have poor management skills due to a lack of training services (Bester et al., 2003; Gwala et al., 2016) and have limited access to working capital (Oduniyi et al., 2020). Lack of access to finance is worsened by banks, which often associate themselves with large-scale commercial farmers who have collateral, better farming track records, and proof of reliable income streams (Myeni et al., 2019).

Limited access to extension services by smallholder livestock farmers, especially those in remote areas, is a key limitation for their commercialization (Baig and Aldosari, 2013). Literature is replete with shortfalls associated with the provision of public extension services to smallholder farmers in developing countries (Akpalu, 2013; Aliber and Hall, 2012; Cook et al., 2021; Gwala et al., 2016; Mapiye et al., 2018). Generally, public extension systems in developing countries are heavily under-resourced, over-stretched, lack skilled human resources, and infrastructural support, and are faced with a decline in investment (FAO, 2017; Meena and Singh, 2013). Further, systems are characterized by high farmer-to-extension officer ratios as the number of trained extension officers is limited (Davis and Terblanche, 2016; Liebenberg, 2015). According to Anandajayasekeram et al. (2007), many governments in East and Southern Africa (ESA) have radically reduced budgets in the agricultural sector, making the provision of public extension services more difficult. In addition, Kerr (2020) notes that the provision of extension services has been disrupted by the COVID-19 pandemic, while Cook et al. (2021) argued the persistent exclusion of social and political factors as a major factor impacting the performance of extension. Therefore, the reduced impact from extension services suggests the importance of characterizing the existing extension approaches and developing measures to revolutionize them (Anandajayasekeram et al., 2007; Myeni et al., 2019).

Agricultural extension and advisory services are pertinent to effecting change and driving the rural development imperative through smallholder agricultural production. Across Africa and Asia, agricultural extension has long been one of the major conduits of agricultural development and transformation, leading to rural poverty reduction and increased food security (Danso-Abbeam et al., 2018; Millar, 2009; Raidimi and Kabiti, 2019). Despite extension having been criticized for failing to deliver such results adequately, it is perceived to have remained the bedrock of smallholder livestock production (Cook et al., 2021). This is because it facilitates access to farming information, inputs, markets, and credit facilities, and promotes the organization and training of smallholder farmers and farmer groups for improved production, and livelihoods (Akpalu, 2013; Deichmann et al., 2016; Myeni et al., 2019; Swanson and Rajalahti, 2010). According to Hanyani-Mlambo (2002) and Danso-Abbeam et al. (2018), the agricultural extension also provides a framework through which challenges constraining smallholder farmers can be identified for further investigation and for the development and modification of solution strategies and policies which guide the farmers.

Given that technical knowledge is generated through research conducted by various research institutions and organizations, the primary role of extension is to customize and facilitate the dissemination of the research findings to farmers (Axinn, 1988; Baig and Aldosari, 2013). Thus, Wesley and Faminow

(2014) and Danso-Abbeam et al. (2018) described the extension as a bridge between scientists, who strive through technical means to find solutions for farmer challenges, and the farmers who employ the solution measures to support their farming systems. Agricultural extension services are provided to smallholder livestock farmers by multiple players and through numerous approaches. Therefore, understanding the major extension approaches being used to support smallholder farmers in Africa and Asia is critical.

2.4 Agricultural extension approaches used in Africa and Asia

Given the envisaged link between research and farmers' needs in modern agricultural systems, effective mechanisms are essential in the provision of technical expert advice to farmers. Due to the diversity of farmer needs, production systems, and agricultural policy objectives, all countries virtually have a mix of extension approaches (Baxter et al., 1989; Eicher, 2007). Thus, over the past few decades, the extension has been tested and deployed using different approaches and strategies (Ali and Haider, 2012; Kidane and Worth, 2016; Marwa et al., 2020). These extension concepts have evolved, and many authors have attempted to fit them into various typologies. Generally, the approaches are not mutually exclusive and can be complementary. The main extension approaches used in Africa and Asia include technology transfer approaches, commodity specialized approaches, participatory extension approaches, cost-sharing approaches, and education institution approaches. Drawing on experiences from Africa and South and East Asia, the following section provides a historical and descriptive synopsis of each of these approaches. Therefore, researchers and policy makers can draw on these lessons to replicate, generalize, and scale up the process of developing new extension approaches or improving the existing ones.

2.4.1 Technology Transfer-Based extension

Towards the beginning of the nineteenth century, colonialism and imperialism gradually introduced various agricultural innovations, and most of them were farm-based technologies that had a limited impact on farmers (Batchelor et al., 2014). However, the rise in agricultural sciences allowed more technology to be created outside the farms by both public and private research organizations. During that time, the research–extension–farmer linkage in Africa and Asia was weak, presenting a gap in disseminating modern research findings (technology). This gave birth to technology transfer-based extension approaches that somewhat involved centralized and top-down planning in disseminating innovations to farmers (Akpalu, 2013; Cook et al., 2021; Nagel, 1997). As a further matter, Alex et al. (2002) noted that technology transfer must not just be restricted to production technologies but should extend to management, administration, and adaptations of the technologies to post-harvest as well as off-farm practices. More importantly, Nagel (1997) implored that the use of technology transfer systems and the commitment by governments to modernization should not discredit the farmers' knowledge base, including their indigenous knowledge. The main technology transfer approaches used in Africa and some parts of Asia include Ministry-based or public extension and the training and visit (T&V) extension approach

2.4.1.1 Ministry-Based or Public Extension Approach

The Ministry-based, also termed public extension approach, has traditionally been the most dominant extension system worldwide (Eicher, 2007; Raidimi and Kabiti, 2019) and was adopted by many countries in Africa and Asia. Invariably, the key responsibility for agricultural extension activities often rests with central governments since agriculture is the state subject (Meena and Singh, 2013). The technology transfer approach is largely supply-driven, efficiency-based, and focuses on specific national objectives, such as increasing yield and reducing production costs on national commodities (Swanson and Rajalahti, 2010). Proponents of this model perceive the planning and management of extension as the sole responsibility of the Ministry of Agriculture (Baig and Aldosari, 2013; Nagel, 1997). The flow of information from the ministry to farmers is usually facilitated through a uniform and nationwide organizational pattern (Nagel, 1997) as prescribed by the national policy.

The basic assumption of the approach is that there is useful technology and information available in the Ministry of Agriculture and is not being used by the farmers (Axinn, 1988). The success of the approach is measured by increases in the production of national commodities by the farmers and the betterment of their families (Axinn, 1988).

One of the major advantages of the public extension approach is that the government can use it to implement national agricultural policies and development programs for smallholder farmers (Axinn, 1988; Cuellar et al., 2006). Under Ministry-based extension, the services are generally free, and farmers can visit the extension offices anytime to seek information and advice (Millar, 2009). However, the approach has been constantly under pressure for its poor performance and the lack of two-way flow of information between extension staff and farmers (Eicher, 2007; FAO, 2017; Mapiye et al., 2019). The approach is continuously beset by the principal-agent arrangement, is costly, and has, therefore, faced an overall decline in investment across Africa and Asia (FAO, 2017; Millar, 2009). Furthermore, FAO (2017) added that the public extension system has institutional inefficiencies associated with bureaucratic processes, lack of accountability, and poor transdisciplinary arrangements. In addition to these factors, the poor performance of the approach could be attributed to a lack of technological interventions such as the use of ICT-based innovations (Magoro and Hlungwani, 2014; Mapiye et al., 2019; Swanson and Rajalahti, 2010).

The public extension approach was reported to be used in various African countries such as Ethiopia, Tanzania, Malawi, Botswana, Senegal, Zimbabwe, and Asian countries such as China, Indonesia, and India (Swanson and Rajalahti, 2010). In Kenya, the National Agriculture and Livestock Extension Programme (NALEP), which started in 2000, has been implemented through the Ministry of Agriculture and the Ministry of Livestock and Fisheries Development. Based on the NALEP internal assessment reported by Cuellar et al. (Cuellar et al., 2006), as many as 80% of the beneficiary farmers agreed that the introduction of the program offered new and good opportunities to them. Over 70% of the farmers claimed that the NALEP approach influenced them to consider farming a business rather than a way of surviving. Further, in Zimbabwe, the Ministry-based extension approach was successfully used to drive the rapid adoption and use of hybrid maize varieties and fertilizers and the initiative doubled maize production under smallholders in six years, 1980–1986 (Eicher, 1995).

2.4.1.2 The Training and Visit (T&V) Extension Approach

According to Nagel (1997), the T&V extension approach is not a separate but one way to organize a Ministry-based extension. The approach was introduced, promoted, and sponsored by the World Bank in Africa and Asia, between 1975 and 1998 (Alex et al., 2002; Baxter et al., 1989; Meena and Singh, 2013; Swanson and Rajalahti, 2010). The T&V approach was generally introduced for transferring the latest agricultural technologies and practices from research to farmers (Duvel, 2000; Marwa et al., 2020). Proponents of the approach believed that transfer of technology could be achieved by increasing and regularizing farmer visits by extension workers, strengthening the supervision of extension programs and workers, providing extension workers with specialized knowledge and resource support, and increasing the extension officers-farmer ratio by recruiting and training more frontline extension staff (GFRAS, 2016;

Nagel, 1997; Ogebe and Adanu, 2018; Swanson and Rajalahti, 2010). Thus, the T&V approach is more centralized, linear, top-down, and based on a hierarchical structure and a rigorously planned schedule followed by extension officers (Axinn, 1988; Kromah, 2016; Nagel, 1997).

The primary assumption of the T&V approach is that technology is developed and validated by researchers, whereas extension practitioners only focus on transferring the technology and its adoption by farmers (Terblanche, 2008). The approach further assumes that, before its implementation, the existing extension staff are poorly trained, not up-to-date, and tend not to regularly visit farmers but rather stay in their offices (Axinn, 1988). Therefore, the success of the approach is tied to the need to increase the yields and total production of targeted national agricultural commodities by individual and small farmer groups in the targeted communities (Kromah, 2016).

One of the major advantages of the T&V approach is that through improved training of extension officers, they can become more knowledgeable and be up to date with information and technology needed by the farmers (Raidimi and Kabiti, 2019). Other advantages include more regular farmer visits and a more professional approach to the provision of extension by the extension staff, which ultimately improves the quality of services. The approach, however, has limitations. It has huge and long-term demands for financial support (Kidane and Worth, 2016; Marwa et al., 2020). As it expands to support more farmers, it requires more support staff, their continuous training and supervision, as well as support infrastructure and transport facilities (Nagel, 1989). This substantially raises the costs of implementing the approach. Moreover, the withdrawal by World Bank created some long-term recurrent budgetary problems for governments which included payments for many permanent workers created by the system and supporting the continuation of extension activities. Due to the relatively high financial outlay required and the withdrawal of funding by the World Bank, the approach was deemed financially unsustainable and rejected by many countries (Kidane and Worth, 2016; Swanson and Rajalahti, 2010).

Most countries that continued using the approach, such as India, Ghana, Mali, Mozambique, Zambia, South Africa, and Zimbabwe, had to initiate various modifications to improve the systems' effectiveness (Eicher, 2007). For instance, in Zimbabwe, the approach was modified to use extension groups instead of targeting only lead farmers, but it was later abandoned (Hanyani-Mlambo, 2002). Based on its implementation, the T&V approach has proved effective in Asia, and this was attributed mainly to the high homogeneity of farming systems and advanced capacity among extension officers and the farmers (Davis, 2008). In this region, the T&V approach was very instrumental in disseminating Green Revolution technologies, especially to farmers in the high-potential, irrigated areas (Eicher, 2007). However, it failed to reach farmers located in rain-fed areas. In Africa, deployment experiences in Kenya and Burkina Faso as reported by Bindlish and Evenson (Bindlish and Evenson, 1997), proved the approach effective in improving farmers' management and raising productivity. In Nigeria, the T&V approach was reported to have boosted the production of cereals as it positively influenced the adoption of improved technologies by farmers (Ogebe and Adanu, 2018). However, experiences in Cote d'Ivoire and Rwanda suggest the model failed to improve farmer productivity and to motivate extension workers (Davis, 2008). According to GFRAS (2016), poor incentives often discourage extension workers from requesting feedback engagements with farmers.

2.4.2 The Commodity Specialized Extension Approach

The commodity specialized extension approach dates to colonial times (Baxter et al., 1989) and is currently being used across Africa and Asia (Eicher, 2007; Kidane and Worth, 2016). Implementation of the approach follows a planned and coherent set of extension procedures designed to promote the production of high-income livestock projects such as domestic-oriented dairying (Baxter et al., 1989) and predominant export or cash crops (Hanyani-Mlambo, 2002; Meena and Singh, 2013). It is also used to promote the utilization of strategic agricultural inputs such as cattle dipping acaricides, crop fertilizers, and herbicides. Commodity specialized extension is centralized (Kromah, 2016; Meena and Singh, 2013) and planned based on a self-financed model with coordination from the government (Hanyani-Mlambo, 2002; Kidane and Worth, 2016; Swanson and Rajalahti, 2010) or private organizations working with contracted farmers (Nagel, 1997). Its primary assumption is that the production of commodity increases by exclusively concentrating on that commodity or utilization of a certain input (Axinn, 1988). It also assumes that overall farming development is realized when modern farming technologies, traditional farming practices, research, input supplies, and marketing are fused and placed under one administration (Kidane and Worth, 2016; Nagel, 1997).

The main strength of the commodity specialized approach is that it has much impact and is more efficient as it can be tailored to specific agro-ecological zones and used to target a fragmented series of farmers (Baxter et al., 1989; Swanson and Rajalahti, 2010). The major weakness of the approach is its inability to support some staple food crops or indigenous livestock species other than those of concern (high-value commodities) (Baxter et al., 1989). Furthermore, (Axinn, 1988) previously noted that farmers' interests are less likely to take priority as compared to those of the leading organizations when using this approach. Consequently, these issues lead to unsustainable utilization of some local resources, poor understanding of whole farm system challenges, and opportunities for farmers which ultimately lead to food shortages (Nagel, 1997). An example of a successful application of the commodity specialized extension approach is the Gujarat Cooperative Milk Marketing Federation in India. It reached over 35 years of existence in 2010, with approximately 2.8 million producers supplying milk from village societies across the country. In Africa, the approach has been successfully used to support exporting cotton and palm oil in Mali (Kidane and Worth, 2016). Thus, smallholder cotton farmers were served by a self-financed cotton research and extension system with government extension services targeting farmers outside the cotton zone (Eicher, 2007). In Zimbabwe, the commodity-based extension was generally organized and supported by private firms or parastatals. It was successfully used to establish out-grower schemes for commodities such as vegetables, tobacco, sugar cane, and dairy cattle (Hanyani-Mlambo, 2002; Kidane and Worth, 2016; SNV, 2014). In countries such as South Africa, the commodity-based extension approach with support from government extension, research universities, and the Industrial Development Corporation (IDC) is being used to promote the re-introduction of Nguni cattle through emerging smallholder farmers (Gwala et al., 2016; Mapiye et al., 2019).

2.4.3 Participatory Agricultural Extension Approaches

Following the decline in government extension services investments in the 1980s-1990s, community-based and participatory extension approaches became increasingly prominent (Baig and Aldosari, 2013; Duvel, 2000; GFRAS, 2016). Participatory extension approaches use farmers to deliver extension services to fellow farmers in group setups with frontline extension officers serving as facilitators, not teachers. Program planning for the approaches is usually controlled locally by farmer groups or farmer associations (Kaur and Kaur, 2018). These approaches recognize that farmers are already key sources of information for other farmers, as argued by Mapiye et al. (2019). By using the existing farmers' social networks and group learning arrangements, participatory approaches promote a reinforcing effect which is essential in mobilizing farmers to embrace local agricultural programs and adopt new technologies (Axinn, 1988; Wesley and Faminow, 2014). Such actions include information sharing, peer consultations, collective problem diagnosis, and decision making (Alex et al., 2002). Implementing these approaches features many regular meetings and demonstrations with small, large, general community groups, or one-commodity specialized groups (Axinn, 1988).

The primary assumption of the participatory approaches is that there are existing indigenous knowledge systems (Burch, 2007) that differ from the scientific knowledge systems, and because of the differences, interacting the two can benefit the farmers (Axinn, 1988). Thus, farmers can be more productive through learning more about what is outside their farming systems. The positive impact of the participatory approaches is measured by the number of farmers actively participating, the continuity of local extension organizations and their systems, and the ultimate benefits that accrue to the community (Axinn, 1988; Kromah, 2016).

One of the main advantages of participatory approaches is allowing farmers to determine their program goals and methods to achieve them (GFRAS, 2016), which increases the programs' relevance to the farmers (Kaur and Kaur, 2018). Another major benefit associated with the approaches is the growth of a mutually supportive relationship between the farmers. Alex et al. (2002) assert that the approaches tap into indigenous farmer knowledge and allow the development of farmer-centric information content that easily applies to other farmers. However, some concerns usually come from the governments indicating that there is a lack of central control of extension programs especially where the ministry of agriculture is not controlling the approaches (Axinn, 1988). Moreover, it becomes more difficult to manage central reporting and accounting for such approaches as programs are subject to change from time to time due to changes in conditions.

Most African countries, including Benin, Malawi, Nigeria, Uganda, and Zambia have adopted, and some, such as South Africa, are developing suitable participatory extension systems to suit local conditions (Akpalu, 2013; Duvel, 2000; Swanson and Rajalahti, 2010). However, effective participation by farmers in these countries seems elusive due to lack of time, uneven political will, and budgetary constraints (Alex et al., 2002; Davis, 2008). This often leads to extension projects that are just nominally participatory but lacking effective empowerment to the farmers and stakeholders. The main participatory extension approaches used in Africa and some parts of Asia include Farmer Field Schools, the project approach, and farming systems research–extension approach.

2.4.3.1 The Farmer Field School Approach (FFS)

The Farmers Field School came to Africa from Asia, where it was successfully used to educate farmers about integrated pest management through farmer group learning (Feder et al., 2004; Swanson and Rajalahti, 2010). The approach is widely accepted in these regions because it is participatory and uses a nonformal education approach where extension officers are more facilitators than instructors (Marwa et al., 2020; Wesley and Faminow, 2014). The approach is group-based and uses iterative and interactive adult learning practices involving periodic meetings (e.g., weekly or monthly) following a planned schedule, observations, and experiential learning to enhance the development and transfer of innovation (Anandajayasekeram et al., 2007; Kidane and Worth, 2016). During the meetings, farmers are assisted in carrying out their research, analysing and testing farm problems, and developing appropriate solutions (Ali and Haider, 2012; Kaur and Kaur, 2018). The fundamental assumption of the FFS approach is that all the initial facilitators have high expertise and are believed to be well capacitated in implementing farmer group learning for farmer capacity building. It also assumes that farmers already have a wealth of knowledge (Anandajayasekeram et al., 2007).

One of the FFS approach's advantages is that it is based more on farmers' discovery and reflections and not on extension workers who normally use blanket recommendations. Further, it is useful in teaching farmers about specialized and knowledge-intensive subjects such as sustainable natural resource management (Swanson and Rajalahti, 2010). Central limitations of the FFS approach include that it has a relatively very high implementation cost, it is labour-intensive, and it reaches a few interested farmers (Abdu-Raheem, K A; Worth, 2016; Feder et al., 2004). According to Abadu-raheem and Worth (2016), the participatory FFS approach, if not carefully guided, can negatively affect community benefits. This is because exclusive reliance on farmers' demands may result in the provision of exclusive technology or services that are often of short-term importance to the farming community as there could be suggested without considering the longer-term externalities such as environmental degradation.

The FFS approach has been implemented in many countries in Africa including the Democratic Republic of Congo, Gambia, Niger, Cameron, Togo, Uganda, Namibia, Tanzania, Nigeria, and Zimbabwe. Evidence from the five case studies in ESA countries (Anandajayasekeram et al., 2007) shows that FFS has contributed to participants' changes in attitudes and perceptions and facilitated the development of new relationships between farmers and researchers extension workers, and community development personnel.

However, its implementation in most of the ESA countries was largely hampered by the inadequate exposure of research and extension staff to the concepts and procedures of the approach. A study by Wandji et al. (2007), in Cameroon, showed that FFS participating farmers had significantly more knowledge about crop husbandry practices than the non-participating ones. In addition to having significantly impacted farmer productivity and income in studies conducted in Kenya, Tanzania, and Uganda, FFS was reported to have also significantly impacted younger farmers, female-headed households, and people with low literacy (Davis et al., 2010). In a study by Ali and Haider (2012) in Faisalabad, Pakistan, more than 90% of the respondents received the latest package of agricultural technologies from agricultural experts through the FFS extension approach. In Nepal, a participatory FFS for a seed selection and multiplication project using new crop varieties led to a 45% increase in yields and improved food access by many households (Wesley and Faminow, 2014). However, even given the positive impacts, studies by Bodnar et al. (2011) and Feder et al. (2004) in India and Indonesia observed incidents of poor knowledge diffusion by FFS-trained farmers to other farmers in the village which had an effect on the improvement of farmer practices.

2.4.3.2 The Project (Integrated) Extension Approach

The project-based extension approach focuses on a defined location (community), for a given period (usually, 5 years) (Alex et al., 2002; Kaur and Kaur, 2018), and emphasizes work with disadvantaged farming groups to alleviate poverty (Nagel, 1997). Invariably, the approach focuses on what is needed by both the beneficiaries and donors (Kromah, 2016) and involves substantial infusions of outside sourced funds and resources to achieve that common goal (Axinn, 1988). Even though substantial financial and technical input support comes from international development agencies, project-based approaches may be controlled at central government levels. The aim is largely to demonstrate the potential of certain new technologies and methods that could be extended and sustained after the project period (Kaur and Kaur, 2018).

The philosophical assumption of the approach is that high-impact farming projects and activities conducted under controlled conditions can continue even after the withdrawal of external support (Axinn, 1988). Thus, measures to boost production under this approach are inextricably linked with a strong emphasis on self-help (Nagel, 1997). In this approach, short-term change at the project site is often used as a measure of success (Kaur and Kaur, 2018).

The main advantages of the project approach are that it enables evaluation of effectiveness and can produce quick results within that small location where it is being implemented, which particularly suits foreign donors (Axinn, 1988). It also allows novel techniques and methods to be experimented with and assessed within the confines of the project (Axinn, 1988). The main drawbacks of this approach are that it has a short time frame, restricts the flow of ideas and innovations outside the project area, and that when the money ends, so do the extension programs (Axinn, 1988). Additionally, since the program is implemented based on a consensus, it must always meet the immediate needs of both parties for success to be realized (Kromah, 2016).

In Nepal, the project approach coordinated through the Ministry of Agriculture and financed by the Asian Development Bank was successfully used to support extension work by fishery officers working on the national aquaculture project in many different locations across the country (Kaur and Kaur, 2018). In Indonesia, the Australian Centre for International Agricultural Research (ACIAR) project was used to improve the productivity and profitability of smallholder shrimp aquaculture and related agribusiness (Millar, 2009). However, it was noted that there was not much support from the district extension office to enable more training on the best management practices to other farmers not participating in the project. In African countries such as South Africa and Zimbabwe, commercialization attempts towards smallholder farmers are also being spearheaded through project extension approaches. The Nguni cattle development program in South Africa (Mapiye et al., 2019) and out-grower schemes on fruit and vegetable export produce in Zimbabwe (SNV, 2014) are supported with project-based extension services. These programs are also receiving much support from the public extension system.

2.4.3.3 The Farming Systems Research-Extension Approach

The farming systems research–extension (FSR-E) approach is centred on solving farmer problems through holistic, systems-based, localized, and iterative technology development and delivery processes (Kaur and Kaur, 2018; Kromah, 2016). Early forms of this approach driven by economists and social scientists began with experiences in Africa, Asia, and Latin America (Bingen and Gibbon, 2012). This was after prescriptive agricultural growth models failed (GFRAS, 2016; Hanyani-Mlambo, 2002). Thus, too often, agricultural extension strategies failed because they could not match the objectives and socioeconomic situations of smallholder farmers, and their agro-ecological conditions (Axinn, 1988). The FSR-E approach aims to develop practices that are tailored to fully meet the heterogeneous demands of the farmers (Bingen and Gibbon, 2012; Nagel, 1989).

The primary assumption of the FSRE approach is that technology that fits the needs of the farmers, particularly smallholders, is not available and can be created locally (Axinn, 1988). Therefore, the agricultural extension content must be developed off-research station but through on-farm research processes involving local farmers and their farms (Bingen and Gibbon, 2012; Kromah, 2016). The success of the approach is measured based on the extent to which farmers adopt the technologies created by the program and continue using them with time (Kromah, 2016).

The main advantage of the FSR-E approach is that first, it provides a model for understanding challenges and constraints faced by the farmers and how they deal with them (Alonge, 1993). Thus, research and extension programs are developed by understanding farmers' needs (GFRAS, 2016) and not from prescriptions by research scientists and extensionists (Meena and Singh, 2013). This also involves farmers' cogent concerns over off-farm activities, issues of food and nutrition security, sustainability, risk reduction, income, and employment opportunities, which form the multiple needs and objectives of the farmers (Kaur and Kaur, 2018). Based on Alex et al. (2002) and Franzel et al. (2015), these activities are a sustainable way of facilitating links between smallholder farmers, researchers, and extension workers. However, according to GFRAS (2016), the main superficial limitation of the FSR-E approach is that it relatively targets crop systems and less livestock-based systems. Additionally, the approach is costly to implement, and results are obtained slowly as it takes more time to study and understand the farm system and its elements in their natural ecosystems (Axinn, 1988).

The FSR-E was well established in Zimbabwe, where it was championed through the Farming Systems Research Unit under the Department of Research and Specialist Services (DR and SS) (Franzel et al., 2015; Hanyani-Mlambo, 2002). Through its extension workers, the Department of Agricultural Technical and Extension Services (AGRITEX) was the one more visible and active at the grassroots level identifying farmers and monitoring on-farm trials (GFRAS, 2016). In a study conducted by Alonge (1993) in Nigeria, a higher proportion of farmers participating in the FSR-E had adopted insecticides, improved rice varieties, and water control techniques than nonparticipants. In the same study, it was recommended that the approach not be discarded but rather re-evaluated and improved because of its importance in improving the farmer–extension–research linkage. The approach has also been well established in countries such as Senegal and

Zambia. However, its introduction in Zambia was associated with high operational costs especially due to transport and payment of daily subsistence allowances (Bingen and Gibbon, 2012). The Southern and Eastern African Association of Farming Systems Research-Extension (SEAAFSR-E) is the biggest regional networking association, which accelerates agricultural and rural development in Southern and Eastern Africa by promoting FSR-E (Mudhara, et al., 2011). It links its members through conferences, seminars, and workshops for building capacity. Some member states of this association where FSR-E is practised include Namibia, Tanzania, South Africa, Kenya, and Uganda.

2.4.4 The Cost-Sharing Extension Approach

Cost-sharing is an emerging extension approach in developing countries (GFRAS, 2016). The approach requires that users pay a fee for accessing agricultural extension services that benefit them (Alex et al., 2002). The approach targets those farmers who do not have the means to pay the full amount for accessing the extension services (Kaur and Kaur, 2018). Its primary purpose is, therefore, to promote the use of agricultural programs that are likely to meet local situations, contribute to farm improvements, and make frontline extension officers more accountable to the interests of the farmers (Kaur and Kaur, 2018; Kromah, 2016).

The approach assumes that non-formal extension educational programs are more likely to achieve the intended goals if beneficiaries (farmers) share the costs of bringing them (Axinn, 1988). It further assumes that rural farmers are too poor to pay the total cost of accessing extension services, so central and regional governments should cover part of the cost. Farmers' willingness and ability to contribute a share towards the cost individually or through their local government units are often used as a measure of success in this approach (GFRAS, 2016).

The main advantage of this approach is that some degree of local control (farmer-centric) in program planning increases the relevance of the program's extension content and activities to the needs and interests of targeted farmers (Axinn, 1988). Generally, this positively influences adoption. Cost-sharing especially involving government–farmer partnerships at national and local levels, is considered one of the most sustainable reforms in delivering extension services because of its ability to generate funding that can support its effective deployment (GFRAS, 2016). Further, it lowers costs incurred by the central government as the costs will be shared by lower levels of the government and local farmers (Axinn, 1988).

However, this approach could be a disadvantage as it does not allow the government to control the program or personnel running it. This becomes worse in situations where the government does not contribute at all towards the costs.

This cost-sharing approach is flexible and can be incorporated into other extension models, including Ministry-based, FFS, and FSR-E (Alex et al., 2002). Anandajayasekeram et al. (2007) recommended the use of a cost-sharing approach to ensure the sustainability of FFS approaches, especially where programs such as the provision of inputs or farmer refreshments are donor-funded for a given period. In Uganda, some Farmer-Field-Schools and National Agricultural Advisory Services (NAADS) programs encouraged the use of cost-sharing approaches (Davis, 2008). Ethiopia started following the cost-sharing model in the late 2000s where, for instance, a Farmer Training Centre (FTC) was established at the local government level serving five villages and serving between 750 and 1500 smallholders. The farmers donated 1–2.5 ha of community land to establish the FTC, including a demonstration farm, and the government paid for the construction of the centre. The farmers also contributed by providing free labor during the construction of these facilities (Davis et al., 2010). In a study conducted to examine the perceptions of farmers and extension professionals about cost-sharing of agricultural technology transfer in Nigeria, more than 80% of the farmers and extension professionals had favourable perceptions (Ozor, et al., 2007). However, Eicher (2007) has argued that there is insufficient evidence to whether smallholder farmers can ever "buy their way out of poverty" by being able to pay for such costs.

2.4.5 The Education Institution Extension Approach

The education institution approach was developed through the United States Land Grant university experiences. The approach was introduced to Africa and Asia by donor agencies such as USAID (Swanson and Rajalahti, 2010). An education institution extension is a decentralized approach that is often implemented by well-established educational institutions (Agricultural schools, colleges, and universities) with the technical knowledge and research capacity to conduct the extension activities especially to poorly resourced farmers (Axinn, 1988; Kromah, 2016). The approach, therefore, forms part of the institution's outreach activities (Kromah, 2016). These remarkable features of the approach extend to user-centric research, quality pre-service and in-service training for extension field staff personnel, and a sturdy linkage between academic teaching and field practices (Nagel, 1997; Swanson and Rajalahti, 2010).

The educational institution extension approach is a facilitation for empowerment approach, which builds practical knowledge in the classroom and technical skills in the farming field. Program planning for the approach tends to be controlled by those who determine the curriculum of educational institutions. Generally, in this model, industry (research), as well as intermediary players, become part of the extension system (Nagel, 1997). The approach's primary assumption is that faculties of agricultural institutions create technical knowledge that is relevant and useful to farmers, and their service staff (teachers) can constantly interact with farmers to transfer knowledge and improve their agricultural teaching skills (Axinn, 1988; Swanson and Rajalahti, 2010). Furthermore, the approach is based on the notion that some farmers who tend to be reluctant to undertake formal or long-term educational courses may in the future change and be willing to acquire some informal theoretical and practical learning. Success in this approach is measured by farmer turnout and the extent of participation by farmers in the institution's extension activities.

The approach's main advantage is that of reducing costs to the national government. Generally, the approach encourages academic institutions to develop policy briefs from their research, and the research outputs contribute to the national extension system. Further, the relationships that exist between specialized scientists and field-based extension workers become good practical training for both (Axinn, 1988). This is because some research can be carried out on farms just like in farming systems research, depending on rapport with farmers. However, one limitation associated with having academic personnel to teach in the field is that they sometimes become too academic, which makes their demonstrations less practical and useful to the farmers. Moreover, some of the research from academics may be scientific curiosity and not address immediate farmer problems.

In some countries, such as South Africa, Zimbabwe, Malawi, and Nigeria, education institution approaches have been designed to be one of the principal mechanisms for disseminating research findings to farmers and linking research with farmers' needs (Alex et al., 2002; Kromah, 2016). However, the institution does not assume full responsibility for extension work (Nagel, 1997) but supports other dominant extension systems (Axinn, 1988; Nagel, 1997). In countries such as India, the education institution approach through a vast network of State Agricultural Universities (SAUs) supports the general extension approach by taking over the extension functions inadequately implemented by the ministry-based extension (Meena and Singh, 2013; Nagel, 1997). Thus, the SAUs are integrating teaching, research, and extension at all levels of university administration and in various districts across the country (Meena and Singh, 2013). For example, the Punjab Agricultural University (PAU) developed its multidisciplinary extension team stationed in each district to engage in adaptive research, training, extension, and consultancy with farmers (Nagel, 1997).

2.5 The South African public extension system

2.5.1 The evolution of public agricultural extension and advisory services in South Africa

South Africa's public extension service evolved since the beginning of the 20th century and was formally established in 1925 (Khwidzhili and Worth, 2019; Koch and Terblanché, 2013). It was established by integrating the term 'extension' into the local agricultural system following recommendations taped from American experiences (Koch and Terblanché, 2013). In that process, the Ministry of Agriculture established a separate Division of Extension and appointed a small group of six service-orientated agricultural advisors to render extension services in all the country's provinces (Khwidzhili and Worth, 2019). Towards the end of the 1920s, cooperative demonstration trials and many field tours were organised for farmers to learn from their peers (Liebenberg, 2015). Primarily, the role of the agricultural extension was the provision of advisory services to improve farmer productivity and their contribution to national food security (Koch and Terblanché, 2013; Liebenberg, 2015).

The South African agricultural extension had two parallel systems, which reflected the dualistic nature of the entire agricultural industry (Liebenberg, 2015; Williams et al., 2008). One was a well-resourced extension system with highly qualified extension personnel to serve the state-backed white commercial farmers. The other system was poorly resourced and served the self-governing black communities (Bantustans) (Akpalu, 2013). Comprehensive support systems from the government and all major institutions were geared towards the commercial sector (Williams et al., 2008).

In the late 1950s, the need for a more scientific approach to extension was realised, and steps to incorporate research and academic training into extension careers were initiated (Koch and Terblanché, 2013). The established faculties of agriculture from the University of Pretoria, Stellenbosch University and Elsenberg College initiated the programmes. Many other universities and agricultural colleges followed the initiative. In further advancing the extension career in higher education, the South African Society for Agricultural Extension (SASAE) was formed as a professional body for supporting extension experts in

1966 at the University of Pretoria (Koch and Terblanché, 2013). Despite these developments, extension services continued to be introduced with highly restraining measures towards the indigenous communities (Akpalu, 2013; DALRRD, 1995).

Formal extension service for black people was established in 1962 following the Extension Methods Workshop conducted in Salisbury (now Harare) (Koch and Terblanché, 2013). This led to the establishment of national agricultural colleges (like Tompi Seleka) to spearhead the training of extension officers to service the former homelands (Khwidzhili and Worth, 2019). Since then, the provision of extension services towards commercially oriented smallholder farmers has remained the role of state agricultural extension officers.

2.6 Agricultural extension policy and implementation frameworks post 1994

Policy formulation and implementation are critical areas of agricultural development that should be fully addressed to create an enabling environment for the revitalisation of extension approaches. This is because the delivery of extension services is driven and informed by policies. The democratisation of South Africa in1994 brought fundamental changes in the policy environment governing extension services (Chaminuka et al., 2005). The policy changes aimed to redress the dichotomous extension system characterised by differentiated levels of farmer support and operations created on racial lines, which the NDA inherited in 1994. The two-tiered service format was more inclined towards the white commercial farmers, giving less attention to the black-dominated territories (Akpalu, 2013; DALRRD, 1995). Besides the existence of parallel extension systems, generally, the government's extension model (transfer of technology approach) was deemed sluggish, ineffective and characterised by poor morale and uneven professionalism among its service personnel (DALRRD, 1995; Machethe and Mollel, 1999; Williams et al., 2008). The system was viewed as a weak link militating against the full impact of the government's agricultural interventions for smallholders (Hlatshwayo and Worth, 2019). In that regard, the post-apartheid interim constitution prompted the establishment of a new agricultural extension policy framework (DALRRD, 1995). Since then, many policies and intervention strategies have been formulated and implemented to address the anomalies and align public extension services with the envisioned agricultural transformation process (Akpalu, 2013; Magoro and Hlungwani, 2014). Therefore, the main policy blueprints and implementation frameworks such as the White Paper on Agriculture, the Norms and Standards, the Extension Recovery

Plan, and the National Policy on Extension and Advisory Services that influenced public extension services since 1994 are, therefore, briefly reviewed.

2.6.1 The White Paper on agriculture policy

In 1995, the White Paper on Agriculture policy was launched to facilitate the new vision of the NDA as it conforms to the new Constitution (Chaminuka et al., 2005; Williams et al., 2008). In achieving this, the paper encapsulated the strategic transformation imperatives of broadening access to agriculture thrust (BATAT) as the guiding perspective (Chaminuka et al., 2005). The primary objectives of BATAT include designing and establishing mechanisms for expanding accessibility to agriculture and extension services by previously under-served farmers. Specifically, the 1995 policy agenda started by critiquing the conventional transfer of technology extension system and argued for promoting holistic extension approaches (Williams et al., 2008). Furthermore, it called for a paradigm shift and a swift reorientation of agricultural research and extension (DALRRD, 1995). Therefore, a new and well-integrated extension service approach (participatory extension) where extensionists act as facilitators and pay full attention to all farmers' needs was recommended to replace the T&V model (DALRRD, 1995; Williams et al., 2008). This recommended Participatory Programmed Extension Approach (PPEA) had five proposed drivers: extension planning and projects, extension linkage and coordination, knowledge and support, education and training, and M&E. All these recommendations were to be complemented by efficient training of extension officers and researchers (Chaminuka et al., 2005).

Some of the specific issues in the White paper include making research and extension development a collaboratively planned process involving all stakeholders and the farmers. Farmers' local knowledge was to be recognised, validated, and complemented by research and appropriate training. Since then, funding of research, extension and training programmes has become the government's sole responsibility. Intuitively, the consistent implementation of some of the White Paper perspectives has seen the gradual reorientation by formerly white serving institutions such as the Agricultural Research Council (ARC) and the Land Bank in addressing the needs of smallholder farmers (Machethe and Mollel, 1999).

2.6.2 The Norms and Standards report

Since the proclamation of the White paper policy, the NDA, through its provincial departments, developed various agricultural development programmes as a response to different national imperatives (Chaminuka et al., 2005). However, gaps in the coordination and delivery of extension and advisory services remained prevalent, and this had to be addressed to ensure the envisaged sustainable rural development (Magoro and Hlungwani, 2014). Competent extension and advisory service approaches were needed to drive the rural agricultural development agendas. The South African government received financial assistance from the Royal Dutch government in 2005 to conduct a national study to develop a feasible extension system (Chaminuka et al., 2005). The outcome from the study showed that there was no single extension model to suit the entire country. Therefore, according to Williams et al. (2008), technology transfer, participatory approach, and needs-based development were all relevant.

Nonetheless, the whole inclusive process culminated in developing minimum criteria for agricultural extension and advisory service known as the 'Norms and Standards' (DALRR, 2007; Magoro and Hlungwani, 2014). These principles were considered essential in forming the standard framework for extension approaches and guiding the extension and advisory services to facilitate government priority programmes (Terblanche, 2008). These principles are summarised in Table 2.1 and are presently being used to guide extension development in South Africa. For instance, as shown in Table 2.1 and reported by Anandajayasekeram et al. (2007), an effective extension system must be demand-driven, relevant, pluralistic, participatory, and more gender-sensitive and pro-poor. Thus, the Norms and Standards cover the need for supporting extension with resources, information creation and dissemination linkages, the extension officers: farmer ratio, training programmes and career pathing. Some recommendations raised through the Extension Recovery Plan include the need for funding to upgrade the number and educational quality of the extension personnel (DALRR, 2007). Even currently, this is an issue raised by various proponents of the extension revolution in South Africa.

Table 2. 1 Summary of the critical principles guiding South Africa's extension and advisory services

Principle	Description
Demand-driven	Extension services should respond to targeted potential farmers' needs while maintaining professional standards.
Relevant	Advice and technologies must be applied within the opportunity realm of resources and the customer's market environment
Pluralistic, flexible, and coordinated extension	Many service providers should be encouraged to participate in agricultural development. This is to be complemented with proper coordination to reduce the negative impact on clients' welfare and duplication of work. The extension and advisory services must efficiently respond to the various needs influenced by the changing socio-economic environment.
Equity	Besides commercial farmers, extension services must be extended to the needy small-scale farmers, women and the disabled to promote equity.
Sound governance	All extension and advisory services programmes and structures must have skilled personnel with clear planning, implementation, monitoring, evaluation and financial accountability procedures.
Effective M&E	All projects must be results-oriented and problem-solving with M&E built-in and consider social, economic, and environmental impacts.
Human and social capital development	The extension and Advisory services must build the capacity of farmers and stakeholders. Emphasis must be on developing targeted and comprehensive capacity towards the clients' problem solving, ownership, and sustainability.
Participatory	Farmers and other beneficiaries must plan, implement, and evaluate their projects to promote ownership and empowerment.
Sustainability	All extension services must provide advice and information that meets the criteria of sustainability, viz. (a) productivity, (b) risks reduction, (c) protection of the environment, (d) economic viability, (e) social acceptability, (f) technical feasibility, and (g) commercial feasibility.
Cooperative governance	Extension services must be regulated and controlled under the framework of cooperative governance. Operational authority and responsibility are allocated to national, provincial local governments.
Priority focused	Government strategic priorities should guide the extension service
Accountability	There should be a communication system with and evaluation by clients on agreed deliverables by extension service and other service providers. The provision of extension and advisory services must be customer-focused
High-quality advisory service	The extension and advisory service must provide high-quality service by incorporating innovations and entrepreneurship into its programmes.
Batho-pele	There must be compliance to the eight Batho-Pele principles in dealing with clients and execution of development efforts.

Summarised based on (Chaminuka et al., 2005)

2.6.3 The Extension Recovery Plan (ERP)

The National Department of Agriculture (NDA), together with all Provincial Departments of Agriculture (PDA) using the Norms and Standards report and recommendations from the Extension Indaba of 2007, embarked on an Extension Recovery Plan (ERP) from 2008 (DALRR, 2007). The ERP framework was developed to capacitate and revitalise agricultural extension services (Khwidzhili and Worth, 2019; Liebenberg, 2015). The plan observed that extension and advisory services had remained a weak link that could not fully support the impacts of government agricultural programmes (Hlatshwayo and Worth, 2019). The ERP initiative was, therefore, anchored by five strategic pillars or objectives, which were to:

i. Ensure visibility and accountability of extension: This was to be achieved by equipping extension officers with tools that can assist them in recording information about the different farmers they engage with (Liebenberg, 2015). This was reinforced by developing a service charter showing the role of extension officers, including the communication protocols. Overall, this was to elevate the poor image of extension among the farmers.

ii. Promote professionalism and improve the image of extension: The pillar aimed at upgrading extension service provision through the affiliation of officers with professional bodies and their participation in professional conferences (presenting scientific or position papers) (Liebenberg, 2015). Some of the core activities involve the provision of mentorship to extension officers and using an award system in recognition of service excellence.

iii. Recruit extension personnel: provinces were expected to conduct more recruitment and capacity-building to comply with recommended extension officer-to-farmer ratios based on the province's respective growth and development strategies (Liebenberg, 2015).

iv. Re-skill and re-orientate extension workers: This involved the design and facilitation of compulsory education and training programmes in technical and soft skills for extension personnel.

v. Provide ICT and other resources: This pillar seeks to develop ICT policy and guidelines to ensure that extension workers have access to computers and other information technology equipment and services they need to carry out their work effectively (Liebenberg, 2015).

2.6.4 The National Policy on Extension and Advisory Services (NPEAS)

The national policy on extension and advisory services drafted in 2014 was developed to create a regulatory agenda to guide the application of agricultural extension approaches in South Africa (Khwidzhili and Worth, 2019). Primarily the policy suggests that extension services should be localised or appropriate to farmers, relevant, efficient, accountable, and promote sustainable agriculture (DALRRD, 2014). Also, the policy emphasised that extension and advisory services are sustainable when they embrace developmental and systems-based approaches which are holistic. Sustainable extension services are guided by a standard set of principles, driven by the needs of farmers and many other actors and should be decentralised and pluralistic and promote the collective dissemination of extension messages (Khwidzhili and Worth, 2019; Terblanche, 2008). The policy agenda recommends that extension personnel be equipped with multidisciplinary skills and exercise accountability to clients at the field level. The NDA was recommended to establish a National Extension Forum composed of members from the public, private and all other stakeholders (Khwidzhili and Worth, 2019). National and district level agricultural extension coordinating forums would then be developed in each province to promote extension services as ascribed in the policy framework (DALRRD, 2014). These would ensure the sustainability of extension delivery systems in promoting sustainable agriculture practices (Myeni et al., 2019).

2.7 Main approach in the provision of agricultural extension in South Africa

South Africa has a very diversified agricultural community; hence the Norms and Standards agenda recommended using different approaches in organising, planning and implementing extension and advisory services (Chaminuka et al., 2005). However, most activities by the government resemble the use of a T&V approach despite policy and new regulatory frameworks suggesting the need to move from conventional supply-driven to demand-led, facilitative and participatory (Duvel, 2000; Worth, 2006). Thus, (Worth, 2008) argued that the basic extension approaches in South Africa have not transformed in any fundamental way. The public extension approach is discussed in the context of its r application to agricultural extension in South Africa

2.7.1 South Africa's public extension approach

This approach has remained a relevant and integral part of agricultural extension in South Africa. The NDA, through the extension directorate office, oversees and drives extension policy formulation and the development of Norms and Standards for extension services. Institutions responsible for developing innovations, such as the Agricultural Research Council (ARC), often use the public extension to diffuse their technology inventions to farmers (Chaminuka et al., 2005). These institutions develop technological extension content, which is either transferred to the extension service or directly to farmers through their subject-matter specialists (Duvel, 2000). Through a decentralised system, the public extension uses its provincial, district and local municipality offices to organise the dissemination of technology to smallholder farmers mainly through the T&V approach (Akpalu, 2013; Duvel, 2000; Koch and Terblanché, 2013). The extension officers/advisors use a fixed schedule, travel to meet individual contact or groups of farmers to share and disseminate agricultural information. The flow of information between extension officers and the farmers is linear and top-down oriented. However, farmers have some form of feedback to extension, particularly during group meetings, but it is not substantial (Mapiye et al., 2019).

2.7.1.1 Limitations of the public extension system in South Africa

Since the reorientation of South Africa's public extension to start focusing on previously disadvantaged farmers some 25 years ago, the system has attempted to move from a supply-driven to a farmer-driven and needs-based system but with little success (Akpalu, 2013; Davis and Terblanche, 2016; Duvel, 2000). The system is marred by a plethora of limitations that are multifaceted (Koch & Terblanche, 2013). The inefficiency of public extension programmes often weakens the ability of smallholder farmers to address day-to-day challenges and effectively respond to sustainability and commercialisation opportunities (DALRRD, 2018; Myeni et al., 2019; DALRRD, 2014; Myeni et al., 2019). Some of the major limitations are, hereby, discussed.

Extension services provided through the public extension approach remain deficient regarding their appropriateness and applicability towards smallholder livestock farmers' individual and unique challenges (Agholor and Ogujiuba, 2021). This is noted in their prescriptive, linear, and top-down nature, with farmers being content receivers (FAO, 2017). This is associated with the weak linkage between farmers, researchers and extension officers is one of the main issues flagged in the current extension draft policy of 2014

(DALRRD, 2014). Lack of farmer involvement in extension content creation, validation and dissemination does not only lead to inappropriate technologies being developed and disseminated but could be a lost opportunity for the empowerment of farmers (Hlatshwayo and Worth, 2019).

The public extension is heavily under-resourced, costly, unaccountable, and often beset by bureaucratic processes that render the T&V model ineffective in supporting the expanding smallholder farming sector (FAO, 2017). Based on Akpalu (2013), extension officers and the extension programmes often lack managerial supervision and support on the ground. This extends to poor incentives towards the field agents on any excellent performance, which ultimately leads to low morale and poor productivity. Lack of innovations and service delivery tools is one of the key challenges compounding poor performance by public extension. For instance, despite calls for the adoption and use of ICTs in extension (DALRRD, 2014), no tangible plans have been put to materialise the agenda across all provinces. Coupled with this is a lack of support resources such as transport and other operational resources.

One of the main challenges is the low extension officers to farmer ratio and the unavailability of skilled extension personnel to support smallholders (Liebenberg, 2015; Raidimi and Kabiti, 2019). Davis and Terblanche (2016) note that it has been constantly reported that many governmental extensionists in the country are underqualified in natural resource management. Therefore, the low effectiveness of extension services is ascribed to the low quality of formal extension education and the inability of in-service training to meet the job support needs (Liebenberg, 2015; Worth, 2008). This can result in low-quality services being offered. The DALRRD, therefore, proposes the need for entrepreneurship training and the training of a new cadre of agricultural extension officers that can efficiently meet the needs of smallholder farmers (Davis and Terblanche, 2016; Raidimi and Kabiti, 2019).

Also, direct and real-time farmer-to-farmer learning or interactivity for skills and innovation exchange are not well-provisioned under the public extension approach as farmers often meet during meetings or field demonstrations. Given this, there are chances that some farmers continue to struggle with challenges such as access to markets or carrying out husbandry practices those other farmers in the community can assist in addressing them.

A review of these extension policy documents and implementation frameworks clearly shows that the effort to turn around the public extension system has been mapped some 25 years ago but not yet implemented. Thus, the public extension approach has remained essentially unchanged despite the implied fundamental shifts, suggesting the need for action to revolutionise existing extension approaches. For example, there is minimal use of ICTs in extension services delivery across all the provinces despite their potential to cut extension delivery costs and increase the number of farmers receiving services. Some extension officers, also, have limited academic and digital skills needed to implement some policy recommendations, such as mainstreaming sustainable agricultural principles. The inefficiency of the public extension system has been discussed by many authors (Mapiye et al., 2018; Worth, 2008), and this justifies the urgent need for strategies that effectively revitalise agricultural extension in South Africa. Information and communication technologies are anticipated to revolutionise the extension approaches used in Africa and Asia and drive smallholder farming towards sustainability

2.8 Towards a revolutionised extension system in developing countries

Failure by the public extension system to effectively support the ever-expanding smallholder livestock sector calls for innovative strategies to revolutionize the system (Magoro and Hlungwani, 2014). This suggests the need for the extension system to be reformed and become more cost-effective, smallholder farmer-centred, and pluralistic (Akpalu, 2013; Terblanche, 2008). The revitalized extension system should embrace the contemporary application of ICTs in extension processes, emphasize the participation of resource-constrained smallholder farmers, rural women's empowerment, as well as the involvement of both farmers and extension officers in adaptive research (Meena and Singh, 2013; Qiang et al., 2012; Tsan et al., 2019).

Figure 2.1illustrates the potential of infusing extension systems with ICTs for sustainable growth of the smallholder farming systems. However, the use of innovative strategies in developing countries is being hampered by the gaping lack of innovative institutions, especially those supporting smallholder farmers (Hazell et al., 2007). Further, there is arguably little research that is being conducted to revitalize the public extension system through innovation. Abadu-raheem and Worth (2016) argued that integrating the country's agricultural policy agendas and innovation with a clear understanding of the needs of the smallholder agricultural sector is a prerequisite for revolutionizing the country's extension. To this end, this study presents a practical expression on the potential role of ICTs such as mobile phones and the internet in revolutionizing public extension and its support towards smallholder farmers.

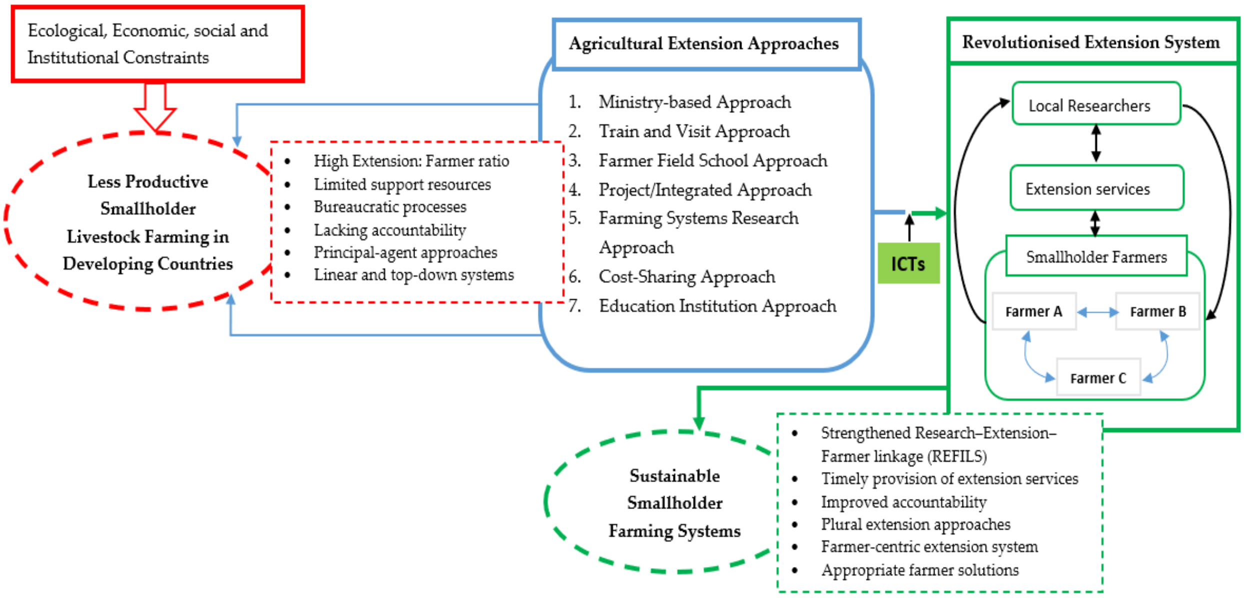

Figure 2. 1 The schematic presentation on the prospects of revolutionizing agricultural extension using ICTs.

2.8.1 Potential for the application of ICTs in revolutionizing agricultural extension

The provision of extension services has continued to evolve with efforts pointing to the application of ICTs (Marwa et al., 2020; Meena and Singh, 2013). Already, the research discourse in this area underscores the potential for ICTs in improving the provision of information and agricultural services towards smallholder farmers (Costopoulou et al., 2016; Marwa et al., 2020; Ogbeide and Ele, 2015). In agricultural innovation, the fast-evolving ICTs and the use of mobile phones have assumed a prominence that has progressively moved beyond mere communications (Henze and Ulrichs, 2016). Such innovation presents a tremendous potential to drive sustainable and inclusive agricultural growth and development among marginalized groups such as subsistence farmers, youths, and female agricultural producers in Africa (AGRA, 2015; Chair et al., 2016; Tsan et al., 2019).

The capacity of ICTs to bring this new momentum to smallholders seems even more compelling due to the current increased investments in research and development and the upsurge of organizations promoting the use of ICTs in rural farming communities, especially in East Africa (World Bank, 2017). Additionally, the ever-increasing availability and uptake of mobile phones (Figure 2.2) present a huge potential for the proliferation of all-inclusive ICT-based innovations among smallholder farmers (Ogbeide and Ele, 2015; Tsan et al., 2019). According to FAO (2018), many countries within SSA have population sizes that are smaller than their total number of mobile-cellular subscriptions. Currently, the SSA region has a mobile subscriber penetration rate of 45% and a mobile internet adoption rate of 24% (GSMA, 2019).

Global Systems for Mobile Connections (2019) reported that the mobile-cellular market for SSA reached 446 million unique subscribers (9% of global mobile subscriptions) in 2018 and is expected to reach 690 million by 2025. Smartphones account for a third of these total mobile subscriptions. Smartphones are expected to take over basic phones as their penetration rate is rising sharply (Trendov et al., 2019), with countries like South Africa expected to exceed 60% penetration rate by the year 2025 (GSMA, 2019).

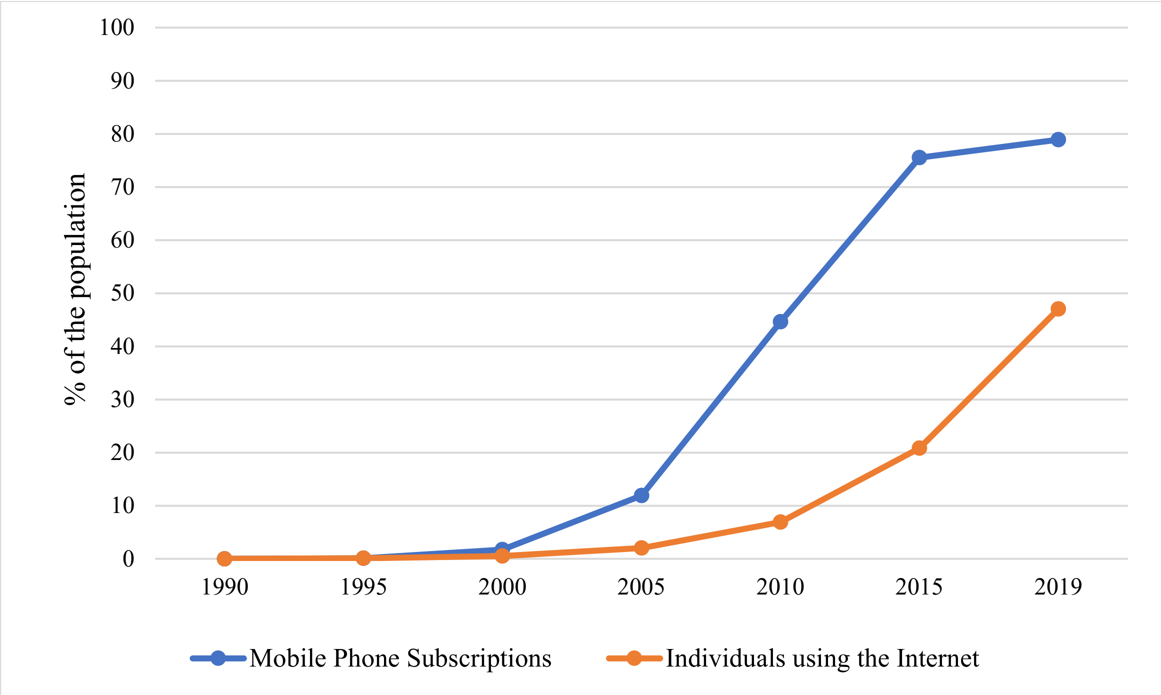

Figure 2. 2 The spread of digital technologies in the SSA region (Source: World Bank Data, 2021).

Internet is also an important component of digitization, and its access by smallholder producers further unlocks the prospects of driving smallholder agricultural production through digital-based strategies. As shown in Figure 2.2, internet use is also projected to continue growing in developing countries and specifically within smallholder agricultural systems (AGRA, 2015). Since most online or internet-based activities take place on mobile phones (GIZ, 2018), the proliferation of mobiles, especially smartphones, could be key in leapfrogging internet use and provision of mobile broadband to smallholder farmers (Qiang et al., 2012). The current mobile internet adoption for SSA is 24% and is expected to continue growing (GSMA, 2019). Chair et al. (2016) reported a significant increase in internet usage and mobile uptake by youth between 2008 and 2012 in countries such as Nigeria, Kenya, South Africa, Uganda, Ghana, Cameroon, Mozambique, Ethiopia, Botswana, and Rwanda.

Apart from that, dozens of agricultural mobile Apps and web-based platforms are being developed and implemented to support agricultural extension delivery and, hence, the transformation of smallholder farmers (Costopoulou et al., 2016; Qiang et al., 2012; World Bank, 2017). Given the need to address heterogeneous and complex farm management issues within the smallholder sector (Costopoulou et al., 2016), these initiatives are constantly evolving (growth of the "App economy") (ITU, 2014). Esoko, established in 2005 in Ghana, which offers marketing, livestock, and crop production advice and weather forecasting to smallholder farmers, has since been replicated and currently operates in 16 African countries, including Nigeria, Sudan, Malawi, Kenya, Uganda, Rwanda, and Zimbabwe (AGRA, 2015). This indicates the importance and potential gains of using ICTs such as mobile phone-based innovations in supporting smallholder farmers.

One of the greatest potentials for revitalizing extension is the fact that smallholder farmers are inherently agricultural innovators, and that they actively engage in sharing innovations among themselves and with extension officers (Burch, 2007; Mapiye et al., 2019). Thus, Deichmann (Deichmann et al., 2016) notes that people have sought advice from one another ever since they started growing crops, raising livestock, and catching fish. However, Anandajayasekeram, et al. (2007) observed that most farmers in the ESA region were willing to share information with fellow farmers, but an internal mechanism was not put in place to compensate for their time. Therefore, the evolution of digital technologies presents new and efficient channels for farmers to exchange innovations and experiences (networking). This existing knowledge and skills sharing can help in expediting the introduction and use of digital technologies by the farmers. Further, ICTs are perceived to foster back-to-back and timely sharing of extension information between farmers, extension officers, and researchers (Baig and Aldosari, 2013; FAO, 2017). Furthermore, the increasing number of mobile phones and broadband connectivity could assist in bringing high-end services closer to the smallholder farmers (World Bank, 2017).

Additionally, such technologies offer opportunities for farmer-centred documentation of local information and innovations which define traditional knowledge (Burch, 2007; World Bank, 2017). According to Ogbeide and Ele et al. (2015), ICTs can also improve access to and the provision of financial services to smallholder farmers. Expansion of the mobile money ecosystem to reach previously unbanked resource-constrained and remote farming populations will be enhanced through increased access to mobile phones and the internet (GSMA, 2019; Henze and Ulrichs, 2016). Moreover, the provision of tailored financial services further presents valuable opportunities such as improving women and youth engagement in agriculture (AGRA, 2015; FAO, 2017). Since most smallholder farmers are women (>50%), and they perform more than 60% of all agricultural activities in the smallholder sector (Tsan et al., 2019), improved access to management information and financial services through digitalization is perceived to increase overall productivity and poverty reduction in rural areas.

According to Costopoulou et al. (2016), efforts to promote the adoption and use of ICTs in agriculture require the active involvement of government agencies and various other agricultural institutions. In addition, the development, adoption, and use of these technologies to support agricultural extension delivery in smallholder farming systems should be supported by effective policy agendas and implementation frameworks. South Africa's NPEAS policy draft has already flagged the introduction of ICTs into extension as one of the government's main objectives (DALRRD, 2014). Thus, extension officers can use the ICT-based tools to gather, retrieve, adapt and disseminate a broad range of agricultural information and services required by smallholder farmers. Policies should also focus on developing infrastructure in the rural farming communities, including expansion of electrification programs and widening access to internet service and mobile network coverage to facilitate efficient extension services delivery (Marwa et al., 2020).

2.9 Conclusions

Smallholder livestock production is an important component of the agricultural economy. However, smallholder farmers continue to lag in commercialization, and this is caused by many challenges and constraints. Some of the major challenges include the shortage of inputs, low formal market participation, land degradation, poor access to financial resources, lack of skills, and limited access to extension services. Agricultural extension invariably helps to bring agricultural information, inputs, and improved technologies and facilitates access to markets and credit facilities by smallholder farmers for improved productivity and livelihoods. Sustainable agricultural development among smallholder livestock farmers can be achieved by adopting and applying extension approaches that fit into the condition of the farmers. Various extension approaches are being used to support the smallholder agricultural development agenda in developing countries. Some of these approaches include technology transfer approaches (Ministry-based and T&V), the commodity specialized approach, participatory extension approaches (FFS and project (integrated) approach, farming systems research and extension approach), cost-sharing approach, and education institution approach. The public extension is the chief source of extension services for smallholder farmers in developing countries; however, it has remained deficient due to various systemic challenges, which are complex and multifaceted. It is deemed to be heavily under-resourced, costly, overstretched, unaccountable, and often beset by bureaucratic processes. The inefficiency of the extension system often restrains farmers from addressing their everyday challenges and seizing various developmental opportunities. Failure by the public extension system to effectively support the ever-expanding smallholder livestock sector calls for innovative strategies to revolutionize the system. To this end, this review emphasized a practical expression on the potential role of ICTs such as mobile phones and the internet in revolutionizing public extension and its support towards smallholder farmers. The proliferation of mobile phones and the internet is envisaged to present an opportunity to develop innovations that improve timely access to localized information and close the farmer–extension–research gap.

2.10 References

Abdu-Raheem, K A; Worth SH (2016) Suggesting a New Paradigm for Agricultural Extension Policy: The case of West African Cuntries. *South African Journal of Agricultural Extension* 44(2): 216–230. DOI: http://dx.doi.org/10.17159/2413-3221/2016/v44n2a425.

Agholor IA and Ogujiuba K (2021) Information Communication Technology: Perception and Adoption of Drought Resilience Strategy for Producers in Driekoppies, South Africa. *Journal of Critical Reviews* 8(02): 1220–1234.

AGRA (2015) *Africa Agriculture Status Report 2015. Youth in Agriculture in Sub-Saharan Africa*. Alliance for a Green Revolution in Africa (AGRA), Nairobi. Available at: http://www.agra.org/media-centre/news/africa-agriculture-status-report--2015-/.

Akpalu DA (2013) Agriculture Extension Services Delivery in a Semi-Arid Rural area in South Africa: The Case Study of Thorndale in the Limpopo Province. *African Journal of Food, Agriculture, Nutrition and Development* 13(4). Available at: https://www.ajol.info/index.php/ajfand/article/view/94600.

Alex G, Zijp W and Byerlee D (2002) *Rural Extension and Advisory Services: New Directions*. Washington DC.

Ali M and Haider MS (2012) An Analysis of Farmer Field School (FFS) as a Potential Source of Advanced Technology Dissemination Among the Farmers of District Faisalabad, Pakistan. *International Jurnal of Suistanble Development* 3(1): 65–70. Available at: http://www.ssrn.com/link/OIDA-Intl-Journal-Sustainable-Dev.html.

Aliber M and Hall R (2012) Support for Smallholder Farmers in South Africa: Challenges of Scale and Strategy. *Development Southern Africa* 29(4): 548–562. DOI: 10.1080/0376835X.2012.715441.

Alonge AJ (1993) *An assessment of the Impact of Farming Systems Research/Extension on the Adoption of Agricultural Technologies in the Middle-Belt Region of Nigeria*. Iowa State University. Available at: https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=11398&context=rtd.

Anandajayasekeram P, Davis K and Workneh S (2007) Farmer Field Schools: An Alternative to Existing Extension Systems? Experience from Eastern and Southern Africa. *Journal of International Agricultural and Extension Education* 14(1): 81–93. DOI: 10.5191/jiaee.2007.14107.

Axinn GH (1988) A Guide on Alternative Extension Approaches. Rome: Food and Agriculture Organisation of the United Nations.

Baig MB and Aldosari F (2013) Agricultural Extension in Asia: Constraints and Options for Improvement. *The Journal of Animal & Plant Sciences* 23(2): 619–632.

Batchelor S, Scott N, Manfre C, et al. (2014) Is there a role for mobiles to support sustainable agriculture in Africa? In: *ICT for Sustainability 2014, ICT4S 2014*, Stockholm, 2014, pp. 272–280. DOI: 10.2991/ict4s-14.2014.33.

Baxter M, Slade R and Howell J (1989) *Aid and Agricultural Extension: Evidence from the World Bank and Other Donors*. World Bank. Washington DC: The World Bank.

Bester J, Matjuda LE, Rust JM, et al. (2003) The Nguni: A Case Study. In: *Community Management of Animal Genetic resources*, Mbabane, Swaziland, 2003, pp. 45–68. FAO.

Bindlish V and Evenson RE (1997) The Impact of T & V Extension in Africa: The Experience of Kenya and Burkina Faso. *Oxford Journals* 12(2): 183–201. Available at: http://www.jstor.com/stable/3986408.

Bingen J and Gibbon D (2012) Early Farming Systems Research and Extension Experience in Africa and Possible Relevance for FSR in Europe. In: *Donhofer, I., Gibbon, D. and Dedieu, B. (Eds) Farming Systems Research in the 21st Century*. New York: Springer, pp. 49–71. DOI: 10.1007/978-94-007-4503-2.

Bodnár F, de Steenhuijsen Piters B and Kranen J (2011) *Improving Food Security: A Systematic Review of the Impact of Interventions in Agricultural Production, Value Chains, Market Regulation and Land Security*. *Ministry of Foreign Affairs of the Netherlands*. The Hague.

Burch S (2007) *Knowledge Sharing for Rural Development: Challenges, Experiences and Methods*. First digi. Quito: Latin American Information Agency.

Chair C, Deen-Swarray M and Khan S (2016) Taking the Microscope to ICT Gender Gaps in Africa. In: *Communication Policy Research South Conference*, Zanzibar, 2016, pp. 1–22.

Chaminuka P, Beintema N, Flahery K, et al. (2005) *The public agricultural research and development spending in*

South Africa- Update. Pretoria. Available at: http://marefateadyan.nashriyat.ir/node/150.

Chingala G, Raffrenato E, Dzama K, et al. (2017) Towards a Regional Beef Carcass Classification System for Southern Africa. *South African Journal of Animal Sciences* 47(4): 408–423. DOI: 10.4314/dsajas.v47i4.1.

Cook BR, Satizábal P and Curnow J (2021) Humanising Agricultural Extension: A review. *World Development* 140. The Author(s): 105337. DOI: 10.1016/j.worlddev.2020.105337.

Costopoulou C, Ntaliani M and Karetsos S (2016) Studying Mobile Apps for Agriculture. *IOSR Journal of Mobile Computing & Application* 3(6): 1–6. DOI: 10.9790/0050-03064449.

Cuellar M, Hedlund H, Mbai J, et al. (2006) *The National Agriculture and Livestock Extension Programme (NALEP) Phase I. Impact Assessment*. Stockholm. Available at: https://www.sida.se/contentassets/7b4d7a21332b4fa8a6e7ff47ec97ee38/0631-the-national-agriculture-and-livestock-extension-programme-nalep-phase-i-impact-assessment_2038.pdf.

DALRR (2007) *Report on the profiling of the current government-employed extension and advisory service officers.* Pretoria, South Africa.

DALRRD (1995) *White Paper on Agriculture- 1995. Agriculture*. Department of Agriculture Land Reform and Rural Development (DALRRD), Pretoria, South Africa.

DALRRD (2014) *National Policy on Eextension and Advisory Services*. Department of Agriculture Land Reform and Rural Development (DALRRD), Pretoria, South Africa.

DALRRD (2018) *Economic Review of the South African Agriculture 2017/2018. Statistics and Economic Analysis*. Department of Agriculture Land Reform and Rural Development (DALRRD), Pretoria, South Africa.

Danso-Abbeam G, Ehiakpor DS and Aidoo R (2018) Agricultural Extension and its Effects on Farm Productivity and Income: Insight from Northern Ghana. *Agriculture and Food Security* 7(1). BioMed Central: 1–10. DOI: 10.1186/s40066-018-0225-x.

Davis K, Nkonya E, Kato E, et al. (2010) *Impact of Farmer Field Schools on Agricultural Productivity and Poverty in East Africa*. IFPRI Discussion Paper 00992. Washington DC. DOI: 10.1016/j.worlddev.2011.05.019.

Davis KE (2008) Extension in Sub-Saharan Africa: Overview and Assessment of Past and Current Models, and Future Prospects. *Journal of International Agricultural and Extension Education* 15(3): 15–28.

Davis KE and Terblanche SE (2016) Challenges Facing the Agricultural Extension Landscape in South Africa, Quo Vadis? *S. Afr. J. Agric. Ext.* 44(2): 231–247. DOI: http://dx.doi.org/10.17159/2413-3221/2016/v44n2a428.

Deichmann U, Goyal A and Mishra D (2016) *Will Digital Technologies Transform Agriculture in Developing Countries?* 7669. DOI: 10.1111/agec.12300.

Duvel GH (2000) Towards an Appropriate Extension Approach for Agricultural and Rural Development in South Africa. *South African Journal of Agricultural Extension* 29(1): 10–23.

Eicher CK (1995) Zimbabwe's Maize-Based Green Revolution: Preconditions for Replication. *World Development* 23(5): 805–818.

Eicher CK (2007) *Agricultural Extension in Africa and Asia*. 48824. Michigan.

FAO (2017) *Information and Communication Technology (ICT) in Agriculture: A Report to the G20 Agricultural Deputies*. Rome: Food and Agriculture Organisation (FAO). Available at: www.fao.org/publications.

FAO (2018) *Gender and ICTs: Mainstreaming Gender in the Use of Information and Communication Technologies (ICTs) For Agriculture and Rural Development*. Rome: Food and Agriculture Organisation (FAO). Available at: https://www.fao.org/documents/card/en/c/I8670EN/.

Feder G, Murgai R and Quizon JB (2004) The Acquisition and Diffusion of Knowledge: The Case of Pest Management Training in Farmer Field Schools , Indonesia. *Journal of Agricultural Economics* 55(2): 221–243.

Franzel S, Degrande A, Kiptot E, et al. (2015) *Farmer-to-Farmer Extension*. 7. Lindau.

GFRAS (2016) *Module 3 : Agricultural Extension Programme Management*. Lindau.

GIZ (2018) *Harnessing the chances of digitalisation for rural development: Lessons learnt from German-funded rural development projects*. Bonn. Available at: https://www.nachhaltige-agrarlieferketten.org/fileadmin/media/Studien/GIZ_Harnessing_the_chances_of_digitalisation_for_rural_deve lopment_2018.pdf.

GSMA (2019) *Mobile Internet Connectivity 2019: Sub-Saharan Africa Factsheet*. Global Systems for Mobile Connections (GSMA), Nairobi. Available at: www.mobileconnectivityindex.com.

Gwala L, Monde N and Muchenje V (2016) Effect of Agricultural Extension Services on Beneficiaries of the Nguni Cattle Project: The Case Study of two Villages. *Applied Animal Husbandry & Rural Development* 9: 31–40.

Hanyani-Mlambo B (2002) *Strengthening the Pluralistic Agricultural Extension System: A Zimbabwean Case Study*. Rome. Available at: http://www.fao.org/3/AC913E/ac913e00.htm.

Hazell P, Poulton C, Wiggins S, et al. (2007) *The Future of Small Farms for Poverty Reduction and Growth*. *The Future of Small Farms for Poverty Reduction and Growth*. 42. Washington DC. DOI: 10.2499/97808962976472020vp42.

Hemming DJ, Chirwa EW, Ruffhead HJ, et al. (2018) Agricultural Input Subsidies for Improving Productivity, Farm Income , Consumer Welfare and Wider Growth in Low- and Middle-Income Countries A Systematic Review. *Agriculture* (41): 1–139. DOI: https://doi.org/10.23846/SR51062.

Henze J and Ulrichs C (2016) The potential and limitations of mobile-learning and other services in the agriculture sector of Kenya using phone applications. In Proceedings of the 12th European International Farming Systems Association (IFSA) Symposium, Social and Technological Trans. In: Shropshire, UK, 2016, pp. 1–11. International Farming Systems Association (IFSA). Available at: https://www.harper-adams.ac.uk/events/ifsa/papers/2/2.5 Henze.pdf.

Hlatshwayo PPK and Worths h (2019) Agricultural Extension: Criteria to determine its visisbility and accountability in resource poor communities. *South African Journal of Agricultural Extension* 126(1): 1–7. DOI: http://dx.doi.org/10.17159/2413-3221/2019/v47n2a499.

ITU (2014) *Digital Opportunities: Innovative ICT Solutions for Youth Employment*. International Telecommunication Union (ITU), Geneva. Available at: http://girlsinict.org/sites/default/files/pages/youthreport_2014.pdf.

Kaur K and Kaur P (2018) Agricultural Extension Approaches to Enhance the Knowledge of Farmers. *International Journal of Current Microbiology and Applied Sciences* 7(2): 2367–2376. DOI: https://doi.org/10.20546/ijcmas.2018.702.289.

Kerr WA (2020) The COVID-19 Pandemic and Agriculture: Short- and Long-run Implications for International Trade Relations. *Canadian Journal of Agricultural Economics* 68: 225–229. DOI: 10.1111/cjag.12230.

Khwidzhili RH and Worth S (2019) Evaluation of the South Africa's Public Agricultural Extension in the Context of Sustainable Agriculture. *South African Journal of Agricultural Extension* 47(1): 20–35. DOI: http://dx.doi.org/10.17159/2413-3221/2019/v47n1a486.

Kidane TT and Worth SH (2016) Different Agricultural Extension Systems Implemented in Africa: A Review. . *Journal of Human Ecology* 55(3): 183–195. DOI: https://doi.org/10.1080/09709274.2016.11907022.

Koch B and Terblanché S (2013) An Overview of Agricultural Extension in South Africa. *South African Journal of Agricultural Extension* 41(1): 107–117.

Kohler M (2016) Confronting South Africa's Water Challenge: A Decomposition Analysis of Water Intensity. *South African Journal of Economic and Management Sciences* 19(5): 831–847. DOI: 10.17159/2222-3436/2016/v19n5a9.

Kromah AT (2016) Extension Approaches in Agricultural Extension. Illinois. Available at: https://meas.illinois.edu/wp-content/uploads/2016/03/Kromah-Abibatu-2016-Extension-Approaches-in-Agricultural-Extension.pdf (accessed 29 April 2021).

Liebenberg F (2015) *Agricultural Advisory Services in South Africa*. Pretoria.

Machethe C and Mollel N (1999) Extension and support services for smallholder agricultural development in South Africa: who is the smallholder farmer? In: *At the crossroads: Land and agrarian reform in South Africa into the 21st century*, 1999, pp. 340–349. Available at: http://repository.uwc.ac.za/handle/10566/4576.

Magoro D and Hlungwani S (2014) The Role of Agricultural Extension in the 21 Century: Reflections from Africa. *International Journal of Agricultural Extension* 02(01): 89–93. Available at: https://www.cabdirect.org/cabdirect/abstract/20143242557.

Mapiye O, Makombe G, Mapiye C, et al. (2018) Limitations and prospects of improving beef cattle production in the smallholder sector: a case of Limpopo Province, South Africa. *Tropical Animal Health and Production* 50(7). Springer Netherlands: 1711–1725. DOI: 10.1007/s11250-018-1632-5.

Mapiye O, Makombe G, Mapiye C, et al. (2019) Management information sources and communication strategies for commercially oriented smallholder beef cattle producers in Limpopo province, South Africa. *Outlook on Agriculture* 49(1): 50–56. DOI: 10.1177/0030727019860273.

Marwa ME, Mburu J, Oburu REJ, et al. (2020) Impact of ICT Based Extension Services on Dairy Production and Household Welfare: The Case of iCow Service in Kenya. *Journal of Agricultural Science* 12(3): 1–12. DOI: 10.5539/jas.v12n3p141.

Mcdermott JJ, Staal SJ, Herrero M, et al. (2010) Sustaining Intensification of Smallholder Livestock Systems in the Tropics ☆. *Livestock Science* 130. Elsevier B.V.: 95–109. DOI: 10.1016/j.livsci.2010.02.014.

Meena MS and Singh KM (2013) *Pluralistic Agricultural Extension System in India: Innovations and Constraints*. 48324. Munich. Available at: http://mpra.ub.uni-muenchen.de/48324/.

Millar J (2009) Adapting Extension Approaches to Cultural Environments in South East Asia: Experiences from Laos and Indonesia. *Extension Farming Systems Journal* 5(1): 143–148. Available at: http://www.csu.edu.au/faculty/science/saws/afbmnetwork/efsjournal/index.htm.

Mudhara, Maxwell; Mutamba, Jeff; Masangano, Charles; Anandajayasekeram P (2011) *Southern and Eastern African Association for Farming Systems Research-Extension (SEAAFSRE)*.

Myeni L, Moeletsi M, Thavhana M, et al. (2019) Barriers Affecting Sustainable Agricultural Productivity of Smallholder Farmers in the Eastern Free State of South Africa. *Sustainability* 11: 3003. DOI: 10.3390/su11113003.

Nagel R (1989) *Agricultural Extension in Africa*. Washington DC.

Nagel UJ (1997) Alternative approaches to organizing extension. In: *B. E. Swanson, R. P. Bentz., & A. J. Sofranko, (Eds.), Improving Agricultural Extension: A Reference Manual.* Rome: Food and Agriculture Organisation.

Oduniyi OS, Rubhara TT and Antwi MA (2020) Sustainability of Livestock Farming in South Africa. Outlook on Production Constraints, Climate-related Events, and Upshot on Adaptive Adapacity. *Sustainability* 12(7). DOI: 10.3390/su12072582.

Ogbeide OA and Ele I (2015) Smallholder Farmers and Mobile Phone Technology in Sub-Sahara Agriculture. *Mayfair Journal of Information and Technology Management in Agriculture (MJITMA)* 1(1): 1–19.

Ogebe FO and Adanu DO (2018) Impact of Training and Visit (T&V) Extension System on Outputs and Income of Cereals Farmers in Zangon Kataf Local Government Area of Kaduna State , Nigeria. *Journal of Research in Business and Management* 6(6): 42–49.

Ozor N Agwu AE Chukwuone NA Madukwe MC and Garforth CJ (2007) Cost-sharing of Agricultural Technology Transfer in Nigeria: Perceptions of Farmers and Extension Professionals, *Journal of Agricultural Education and Extension*, 13:1, 23-37, DOI:10.1080/13892240601162072

Qiang CZ, Kuek SC, Dymond A, et al. (2012) *Mobile Applications for Agriculture and Rural Development*. Washington DC.

Raidimi EM and Kabiti HM (2019) A Review of The Role of Agricultural Extension and Training in Achieving Sustainable Food Security: A Case of South Africa. *South African Journal of Agricultural Extension* 47(3): 120–130. DOI: http://dx.doi.org/10.17159/2413-3221/2019/v47n3a520.

SNV (2014) *Rural Agriculture Revitalisation Program: Horticulture Sub-Sector Study Report*. Harare.

Swanson BE and Rajalahti R (2010) *Strengthening Agricultural Extension and Advisory Systems: Procedures for Assessing, Transforming, and Evaluating Extension Systems*. *Agriculture and Rural Development*. 44. Washington DC. Available at: http://siteresources.worldbank.org/INTARD/Resources/Stren_combined_web.pdf.

Terblanche SE (2008) Towards an Improved Agricultural Extension Service as a Key Role Player in the Settlement of New Farmers in South Africa. *South African Journal of Agricultural Extension* 37(1): 58–84. DOI: 10.4314/sajae.v37i1.3726.

Thamaga-Chitja JM and Morojele P (2014) The Context of Smallholder Farming in South Africa: Towards a Livelihood Asset Building Framework. *Journal of Human Ecology* 45(2): 147–155. DOI:

10.1080/09709274.2014.11906688.

Trendov N, Varas S and Zeng M (2019) *Digital technologies in Agriculture and Rural Areas*. Rome. DOI: 10.4324/9780429507533-13.

Tsan M, Totapally S, Hailu M, et al. (2019) *The Digitalisation of African Agriculture: Report 218-219*. Wageningen.

Udmale P, Ichikawa Y, Manandhar S, et al. (2014) Farmers' Perception of Drought Impacts, Local Adaptation and Administrative Mitigation Measures in Maharashtra State, India. *International Journal of Disaster Risk Reduction* 10. Elsevier: 250–269. DOI: 10.1016/j.ijdrr.2014.09.011.

Wandji N, Binam N, David S, et al. (2007) Assessing Potential Impact of a Farmer Field School Training on Perennial Crop in Cameroon. In: *AAAE Conference Proceedings*, Accra, 2007, pp. 253–257. Available at: https://s3.amazonaws.com/academia.edu.documents/34739212/Njankoua.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1507684835&Signature=x5CchiC%2FUPyujMPkrEbIjgpZs%2F4%3D&response-content-disposition=inline%3B filename%3DAssessing_Potential_Impact_of_a_Far.

Wesley A and Faminow M (2014) *Background Paper: Research and Development and Extension Services in Agriculture and Food Security*. *ADB Economics Working Paper Series*. 425. Mandaluyong. DOI: 10.2139/ssrn.2558920.

Williams B, Mayson D, Epstein S, et al. (2008) Extension and small holder agriculture Key issues from a review of the litera t ure.: 28.

World Bank (2017) *ICT in Agriculture: Connecting Smallholders to Knowledge, Networks, and Institutions*. Updated Ed. Washington DC: The World Bank.

Worth SH (2006) Agriflection: A Learning Model for Agricultural Extension in South Africa. *The Journal of Agricultural Education and Extension* 12(3): 179–193. DOI: 10.1080/13892240600915488.

Worth SH (2008) an Assessment of the Appropriateness of of agricultural extension education in South Africa. PhD Thesis. School of Environmental Sciences, Faculty of Science and Agriculture, University of KwaZulu-Natal, Pietermaritzburg.

Chapter 2 (b): Information and Communication Technologies (ICTs): The Potential for Enhancing the dissemination of Agricultural Information and Services to Smallholder Farmers in Sub-Saharan Africa

Abstract

The transformation of smallholder farming is poised to be one of the key drivers of achieving the dual objectives of food security and poverty reduction in SSA. Smallholder farmers account for between 60-80% of the food produced in the region but face many challenges that impede their productivity. Such challenges include a lack of timely access to appropriate agricultural information and services, which results in poor decision-making, particularly in addressing challenges and responding effectively to opportunities. In that context, the effective use of ICTs in improving accessibility to appropriate agricultural information and services presents substantial prospects for transforming the productivity and livelihoods of the farmers. Currently, the region experiences massive penetration and propagation of mobile and web-based applications. However, there is a dearth of compelling, comprehensive reviews evaluating their importance in enhancing agricultural information and services dissemination to smallholder farmers. Therefore, the current review explores the potential of enhancing agricultural information and services dissemination to smallholder farmers through ICTs and highlights gaps in their development and deployment in SSA. Five existing mobile applications used to disseminate agricultural information and services to smallholder farmers were identified, and their advantages, limitations, and opportunities were discussed. These were Esoko, iCow, Community Knowledge Workers, WeFarm and DigiFarm. The development and deployment of user-driven mobile applications that provide curated skill-sharing platforms, encourage farmers to give feedback to extension systems in real-time and mainstream women and youths participation in agriculture are recommended.

2.1 Introduction

The dynamic revolution and widespread of ICTs such as web-based and mobile applications continue to generate new prospects for transforming smallholder farming systems in SSA (Emeana et al., 2020; Hopestone, 2014; Tsan et al., 2019). According to Verdier-chouchane and Karagueuzian (2016), ICT is

"…...a heterogeneous set of goods and services used to produce, process, distribute and transform information". It comprises "…. any device, tool, or application that permits the exchange or collection of data through interaction or transmission" (World Bank, 2017). Within agricultural industries, particularly farming systems, ICTs are perceived as vectors of grassroots innovation, transformation, and socio-economic growth (Drafor, 2016; SNRD, 2016). Thus, their universal revolution has demonstrably improved how farmers work, access information, connect and be productive (FAO, 2018; Isenberg, 2019). Broadly, web-based and mobile applications can be used to empower the disadvantaged and strategic groups such as youths and women in rural agriculture by re-engaging them and improving their access to information and support resources (Henze and Ulrichs, 2016; ITU, 2020; Verdier-chouchane and Karagueuzian, 2016).

Across the SSA region, agriculture is vital in alleviating poverty, and driving economic growth and social development (Hopestone, 2014). It constitutes the highest fraction of the employed population (about 65%) (AGRA, 2015). In the SSA region, smallholder farming remains the predominant form of agriculture representing nearly 80% of its total farmers (Verdier-chouchane and Karagueuzian, 2016) who produce close to 80% of the food (Lowder et al., 2014; Ogbeide and Ele, 2015; Tsan et al., 2019). However, the region continues to be faced with the highest food insecurity risk compared to other regions with its population being projected to increase 2.5-fold by 2050 (Tsan et al., 2019). Considering these predictions and the potential of smallholders in leveraging agrarian change and alleviating rural poverty and hunger, improving the viability of these small and marginal farms becomes critical (Fan and Rue, 2020; Kamara et al., 2019).

For a long time, transformation of smallholder farming systems in SSA has been difficult to achieve. Thus, most smallholders are not as productive and profitable as they could potentially be and their production systems are still in subsistence and semi-subsistence farming (FAO, 2017; Henze and Ulrichs, 2016; Ogbeide and Ele, 2015). The transformation of smallholder farming has been hampered by many factors, including lack of markets and unfair market conditions, poor access to advanced technologies, frail infrastructure, gender imbalance, and political instability (Fan and Rue, 2020; World Bank, 2017; Zyl et al., 2014). Also, climate variability and the prevailing drought conditions have grossly affected the viability of smallholder farming systems in the region (Anadozie et al., 2021; Chingala et al., 2017; Rust and Rust, 2013). However, these challenges are compounded by a set of limitations associated with poor access to relevant and timely agricultural information and services (Mapiye et al., 2019; Van Schalkwyk et al., 2017).

This is informed by the compelling philosophies that farmers need more localised information and services because agriculture is increasingly becoming complex and knowledge-intensive (Ali, 2012; Batchelor et al., 2014; SNRD, 2016). Literature has many studies (Amer et al., 2018; Consolata, 2017; Drafor, 2016; Mapiye et al., 2019; SNRD, 2016) describing how limited access to information and services constrain farmers' decision-making process and increase their vulnerabilities to climate change risks.

Mbanda-Obura, Tabu, Amudavi, and Obura (2017) and Anadozie et al. (2021) suggest that besides instigating diverging perceptions and sub-optimal choices by farmers, lack of appropriate information weakens their ability to control their everyday challenges and optimise the use of available resources. According to Ochieng, et al., (2014), information asymmetry hampers access to markets, adoption of modern technologies, and farm productivity among smallholder farmers. One of the ways to improve access to agricultural information and services in smallholder farming systems is to adopt and use ICT-based innovations, especially mobile and web-based strategies (Consolata, 2017; Ogbeide and Ele, 2015; Emeana et al., 2020).

The use of ICT-based technologies presents opportunities for creating, disseminating, and sharing customised information among farmers and across the farmers-extension-research nexus (FAO, 2017; Mapiye et al., 2019). Mobile technologies can boost peer-to-peer interactivity and hence initiate the creation of immersive and user-driven participatory solutions (Aker and Mbiti, 2010; FAO, 2018). Past studies have so far estimated some positive contributions from using mobile phone technologies to support smallholder farmers in Africa (Emeana et al., 2020; Hopestone, 2014; Nakasone et al., 2013). In this context, it is important to continuously invest and innovate towards developing and deploying mobile technologies to support smallholder transformation.

A report by FAO (2017) argued that existing research on SSA's agricultural digital information and services delivery system is still fragmented and experimental. There are very few reviews critiquing existing mobile and web-based applications deployed for smallholder farmers in SSA. This study, therefore, sets out to explore the potential of mobile and web-based technologies and gaps in their deployment in SSA in supporting the dissemination of agricultural information and services towards smallholder farmers. In achieving this aim, the review seeks to answer some critical questions using relevant case studies. The initial question is on mobile and web-based technologies' relevance and general impact on smallholder agriculture and rural development in the SSA region. The second question explores trends and current statistics on the revolution of mobile phones, network and internet availability, and accessibility by smallholders in the region. This will be followed by a question on factors constraining the adoption of mobile and web-based technologies by smallholders in the region. Also, the review addresses the central questions of what mobile and web-based technologies are available to improve the provision of information and extension services to smallholder farmers and the issues surrounding their scalability and areas of origin. Answering this question provides a critique of case studies of ICT-based initiatives currently being commercially used to support smallholder farmers. The last question explores the gaps and general limitations of the existing Apps while providing a prospective analysis and concise recommendations for researchers and future technology developers.

2.2 Review methodology

The review included mainly research publications from accredited journals and reports from regional and world institutions which were published between the years 2006 and 2021. The search was conducted in 5-year periods (2006–2010; 2011–2015; 2016–2021). The proportions of articles obtained for each period were 4%, 34%, and 62%, respectively, with the total number of articles used being 94. Major electronic databases such as Google Scholar, Science Direct, AGRICOLA, SciELO, and SpringerLink were systematically searched to identify all eligible articles. The first search was conducted in March 2019. More searches were then repeated in August 2020 and March 2021. For the initial search, Boolean search strings 'Mobile phone applications' AND 'ICTs revolution' AND 'information dissemination' AND 'smallholder farmers' AND 'Sub-Saharan Africa' were used. Thereafter, the strings 'mobile phone penetration' AND 'internet connectivity' AND 'mobile network accessibility' AND 'constraints' AND 'smallholder farmers' AND 'Sub-Saharan Africa' were also used.

The inclusion criteria for the five mobile applications (Esoko, iCow, Community Knowledge Worker, WeFarm, and DigiFarm) selected for this review was based on their operational scale in various countries, commercial potential and used in the dissemination of information and services in SSA. The search was then narrowed to focus on these selected tools. For example, a combination of the terms "Esoko", "application", and "Africa" was used to search for articles about the Esoko mobile application. Articles providing detailed information on the establishment aims, specific uses (e.g., provision of information and services), replicability and scalability, and technology limitations were retrieved.

Full-text articles were accessed for free through links provided by the search engines visited and where the article was not found, websites such as ResearchGate, which gives an option to request full texts directly from authors, were utilized. The research articles and reports that might have been dropped from the first search were retrieved through the Google search engine. Also, reference lists of included articles were checked, and this was followed by performing a citation tracking in which all the articles that cite each of the included articles were tracked. In some cases, the published information regarding the five innovations was not consistent, so the review presents the available information for each innovation.

2.3 The relevance of ICTs to smallholder agriculture and rural development in SSA

Rural development is a dynamic concept that suggests the positive economic, social and human transformation of a group of people from a previous situation (Wiggins et al., 2018). It is not cultivated from a single activity but stems from various interventions contributing to rural growth. Smallholder farming is one of the essential activities driving rural development and natural resource conservation (Kamara et al., 2019) and igniting growth in the mainstream parts such as the non-farming economy (Wiggins et al., 2018). This could imply that the concepts of 'agrarian change' and 'rural development' are co-dependent. It is, therefore, imperative to constantly promote agricultural development especially through the transformation of smallholder farming systems.

Agricultural extension remains the mainstay of smallholder agricultural systems and hence rural development in SSA (Danso-Abbeam et al., 2018; Raidimi and Kabiti, 2019). It is responsible for transferring agricultural information to farmers as well as improving their capacity building, productivity, and well-being (Akpalu, 2013; Deichmann et al., 2016;). Within smallholder production systems, the public extension is the key source of information and advisory services for farmers (Ali, 2012; Mapiye et al., 2019; Raidimi and Kabiti, 2019). However, given its linear and top-down approach and many limitations such as lack of support resources and high farmer-to-extension ratio, the public extension has failed to effectively support the smallholder sector (Ali, 2012; Consolata, 2017; FAO, 2017). Therefore, harnessing strategies to reform and improve the efficiency of extension systems in delivering information and services to smallholders is critical.

Clinically, in the past few decades, discourses on the potential strategies which can be used to improve the efficiency of extension in delivering information to smallholders point to the adoption and utilisation of ICTs such as mobile and web-based technologies (Consolata, 2017; Hopestone, 2014; Quandt et al., 2020). Various ICT-based initiatives have, therefore, been developed and are widely distributed across the SSA region. According to Tsan et al. (2019), about 43 of the 49 countries in SSA have some form of digital for agriculture-based solutions, with more than 50 per cent of the innovations being headquartered in Kenya. Currently, digital for agriculture solutions have registered more than 33 million smallholder farmers and pastoralists across Africa. Zyl et al. (2014), World Bank (2017), and FAO (2017) state that the increasing ubiquity of these technologies and broadband connectivity is helping to reduce poverty by bringing high-end services closer to rural farmers. Infusing extension with digital technologies can, therefore, promote and hasten back-to-back interactions (feedbacking) between farmers and extension. Also, given that smallholder farmers are invariably innovators who actively engage in skills and innovations sharing (Drafor, 2016; Mapiye et al., 2019), the evolution of ICTs presents new and efficient channels for strengthening this, especially among the remotely located rural farmers (Daum et al., 2018). Furthermore, these new interventions allow for the capturing, organizing, and preserving traditional or local knowledge shared by farmers (World Bank, 2017).

Apart from improving the extension service delivery, the emerging ICTs can promote the development of initiatives bringing financial services such as mobile money to smallholder farmers in SSA (Emeana et al., 2020; Kikulwe et al., 2014; Verdier-chouchane and Karagueuzian, 2016). Financial service initiatives such as Agrinet from Uganda, M-Pesa in Kenya (World Bank, 2017), EcoCash in Zimbabwe (Ifeoma and Hove, 2015), and eWallet in Nigeria (Adebo, 2014) are critical innovations promoting the participation of smallholder farmers in agricultural value chains through access to mobile banking services. These services are valuable opportunities for improving gender equality (FAO, 2017) and youth engagement in agriculture (AGRA, 2015) and have a positive net impact on household income (Kikulwe et al., 2014). In a study by Suri and Jack (2016) and Kikulwe et al. (2014) in Kenya, the use of mobile money services reduced extreme poverty in female-headed households by 22% and positively impacted household income of smallholder farmers, respectively. Thus, improved access to finance by women farmers can increase agricultural productivity and reduce poverty levels in the region (FAO, 2018). This is because women constitute the majority of smallholder farmers (Isaya et al., 2018; Tsan et al., 2019) and perform more than 60% of all agricultural activities in the smallholder sector (Zyl et al., 2014).

Digitalisation is strengthening the participation, interactions, and market linkage among smallholder producers leading to improved productivity and profitability (Hopestone, 2014; Krone et al., 2016; Qiang et al., 2012). Thus, many empirical studies have shown that the innovations can reduce the time and costs of travelling by farmers, facilitate their social learning and generate employment opportunities for them and their families (Consolata, 2017; ITU, 2014; Quandt et al., 2020). In a study conducted in four rural farming communities in Tanzania by Quandt et al. (2020), the use of ICTs like mobile phones was reported by 60% of the respondents to have helped them increase profits from farming. Farmers used phones to locate cheaper and nearer fertiliser sellers and recruit cheaper transport service providers, saving them both time and money. Previously, Aker and Mbiti (2010), found that the use of mobile phone-enabled technologies reduced search costs of agricultural price information by 50 per cent within Niger's rural farming sector. Besides improving access to market information by smallholders, ICTs are perceived to help disrupt monopolistic market activities (Aker and Mbiti, 2010). This eventually promotes the growth of small formal markets, which largely support smallholders. Despite fast technological advancement and the supposedly discussed new opportunities for developing smallholder agriculture, the interventions largely depend on the accessibility to mobile phones, the internet, and mobile connectivity, especially by the rural poor.

2.4 Mobile phone subscriptions and network accessibility in SSA

For the past two decades, people in SSA, particularly the rural poor are increasingly more interconnected and this is primarily driven by access to mobile phones (Deichmann et al., 2016; Kikulwe et al., 2014). About 81% (995 million) of Africans had mobile connections in 2018 (GIZ, 2018; Kemp, 2019). According to GSMA (2020), the mobile-cellular market for SSA reached 477 million subscribers (6% of global mobile subscriptions) at the end of 2019 and is expected to reach 1 billion subscribers by 2024. Many countries in the SSA region have more mobile-cellular subscriptions than their human population sizes (FAO, 2018; Kemp, 2019), with an approximate mobile density of 230 mobile subscriptions per 100 inhabitants. Smartphones account for a third (340 million) of mobile phones and are slowly taking over the "feature phones". The region's mobile subscriber penetration for all mobile phones is 50% (GSMA, 2020). The smartphone average adoption rate continues to rise and has reached 50% in 2020 (GSMA, 2020). The rate is expected to be much higher in some economically leading countries, such as South Africa with over 90%

penetration (ICASA, 2020). This is because affordable smartphone handsets are becoming widely available on the market and are compatible with popular Apps and connections to 4G and 5G networks, which gives a much faster and better browsing experience than the traditional feature phones (Wyrzykowski, 2020). Daum et al. (2018) show that smartphone Apps can be designed to serve as reliable, affordable, and participatory data collection tools in complex smallholder farming systems. The use of more comprehensive mobile-phone-based technologies by smallholder farmers could, therefore, help them access the information necessary to support such complex farming systems (Krone et al., 2016).

The high number of mobile phone subscriptions, however, does not necessarily equate to an even distribution of the devices among the population. Regarding location within the country, gender, and youth dynamics, for example, SSA is highly characterised by unbalanced and wide disparities in terms of mobile phone ownership (Trendov et al., 2019). In some countries, rural people have far much less accessibility to mobile phones than urban dwellers (Nakasone et al., 2013). In Zimbabwe, despite a small gap, mobile phone use is higher in urban than rural areas (97% vs. 85%) (Moyo-Nyede and Ndoma, 2020). Furthermore, accessibility to mobile phones across the region varies considerably across countries. This varies from as high as 90% in Zimbabwe (Moyo-Nyede and Ndoma, 2020), 40% in Burkina Faso, and to as low as 15% in Niger, Chad, and Mauritania (Tsan et al., 2019). This vicious gap also characterises mobile phone ownership between men and women (Henze and Ulrichs, 2016; Messenger, 2018; Steinfield and Wyche, 2013). Sub-Saharan Africa's women are 15% less likely to own a mobile phone than men. Only 25% of the women who represent nearly 50% of all smallholder farmers in the region are registered users of digital for agriculture solutions (Tsan et al., 2019). Interestingly, a study by Isaya et al. (2018) shows that more than 86% of the female farmers in the Hai and Kilosa districts in Tanzania owned or has access to mobile phones. However, even if the majority of the women own mobile phones, they less often use them and have access to fewer services beyond voice communication than men (Isaya et al., 2018; Isenberg, 2019). On the other hand, a report by World Bank (2017) shows that many female farmers under *Esoko*'s mobile market information service did not own mobile phones and had to borrow from their children and/or husbands. Also, a study by Messenger (2018) shows that there was a gender divide in both Northern and Central Malawi as nearly 40% more men were owning mobile phones than women. Most women and girls who did not own mobiles had to share with their husbands, fathers, or mothers-in-law. Limited use of mobiles by women is worsened by the high costs of mobile phone data and airtime (Messenger, 2018). This gap, therefore, disproportionately reduces the connectivity to business opportunity which reduce the productivity of women and the region. Moreover, there is little progress in trying to reach female farmers and reduce such gender asymmetries across the region (Krell et al., 2021). Isenberg (2019) argued that women especially from rural areas have remained an afterthought when it comes to ICT policy and private sector outreach.

Mobile network coverage continues to exponentially expand in SSA. The coverage complements the full functioning of mobile phones and hence their support towards smallholder agricultural development. Recent GSMA and ITU reports issued in 2020 have shown that more than 90 percent of the world population have access to or are currently within range of a mobile broadband signal, while more than one-third have access to 3G coverage (GSMA, 2020; ITU, 2020). In SSA, 3G network coverage expanded to 75% compared to 63% in 2017, while long-term evolutions (LTE) such as the 4G doubled to nearly 50% compared to 2017 (GSMA, 2020; Wyrzykowski, 2020). However, the region still accounts for 40% of the world population not covered by the mobile broadband network (GSMA, 2019). Countries such as Guinea Bissau have a very low proportion of their population (8%) with access to network signal compared to other developed economies including, the EU Member States, Barbados, and United Arab Emirates with 100% coverage (Trendov et al., 2019).

Despite the region still lagging compared to others, the 5G era has begun and is gaining momentum. Thus, by end of 2025 SSA is expected to have just under 30 million mobile 5G connections (GSMA, 2020). Key trials on 5G have been conducted elsewhere in SSA, including countries such as Gabon, Kenya, Nigeria, and Uganda. The first major 5G networks were launched by Vodacom and MTN in 2020 to offer 5G mobile and fixed wireless access (FWA) services to many locations across South Africa (GSMA, 2020). However, a key concern is that despite all urban areas being virtually covered by a mobile broadband network, many gaps subsist in rural and remote areas where most smallholder farmers are located. In this context, innovative strategies, novel business models and supportive government and regional policy frameworks should be key in improving the commercial feasibility of increasing mobile internet broadband networks.

2.5 Internet connection in SSA

The use of the internet has continued to grow across the world (AGRA, 2015; World Bank, 2016). Mobile internet adoption for SSA was standing at 26% at the end of 2019 (GSMA, 2019). Accessing the internet unlocks the possibility of driving smallholder agricultural production through ICT-based strategies. The continuous penetration of mobile phones is key in advancing the use of the internet especially among the smallholder farmers located in rural areas (Qiang et al., 2012; Wyrzykowski, 2020). This is because much of the online activities take place on mobile phones (GIZ, 2018; ICASA, 2020). In 2017, nearly 50% of the global population had access to mobile phone internet, and most of them were in Africa and Asia (Trendov et al., 2019). In Africa, countries such as Kenya, Nigeria and Ghana registered the highest rate of mobile internet traffic in 2019 (Trendov et al., 2019). According to ICASA (2020), mobile phones are the most used means of accessing the internet by the majority of rural households in South Africa (45%). However, the internet connection is much lower in the majority of SSA countries with cases such as Ethiopia with only 4% of its population accessing the internet (Tsan et al., 2019).

Despite more and more urban people across the region becoming connected, rural people have remained disconnected and isolated. Thus, a huge gender gap and the rural-urban gap in mobile internet use persist in SSA (Wyrzykowski, 2020). The rural-urban gap in internet use is standing at 60% (Wyrzykowski, 2020). Approximately 40% fewer women are likely to use mobile internet than men in the region (ITU, 2020). However, in China, the proportions are almost similar for males and females, with a marginally higher figure for females (52.4%) (Trendov et al., 2019). This implies that SSA has a larger gender gap in terms of internet access than other regions, indicating the importance of programs targeting women to increase internet usage in the region. Youths are important users of the internet in SSA. About 40% of the youths use the internet in Africa and the rate of adoption is sharply increasing (ITU, 2020). Given the sharp rise in internet usage and mobile uptake by the youth in developing countries, promoting youth engagement in agriculture could substantiate the adoption of ICTs in smallholder farming. However, in a study by Messenger (2018), mobile-based internet was the least used form of communication even in areas where nearly 50 percent of the people owned internet-enabled mobiles.

Trendov et al. (2019), argued that the penetration of mobile phones and the delivery of internet and mobile network connectivity especially in rural areas of SSA has remained a tall order and this is due to several constraining factors. It is, therefore, important to identify and address these factors as efforts seeking to improve the implementation of ICTs.

2.6 Factors constraining the use of mobile phone and web-based technologies by smallholder farmers in SSA

Illiteracy and lack of digital skills among smallholder farmers and in some cases extension officers constrain the use of ICTs (Messenger, 2018; Trendov et al., 2019). Owning and using a mobile phone may not be sufficient to justify productivity among farmers. Instead, farmers' skills level in operating the phone and understanding its features are critical (Quandt et al., 2020). Many studies have argued that lack of skills impedes the adoption of technologies and reduces the opportunities for smallholder farmers to access agricultural information and services in real-time (Henze and Ulrichs, 2016; ITU, 2020; Misaki et al., 2018). Together with Southern Asia, SSA has the lowest digital literacy rates (Trendov et al., 2019) with skills among smallholder farmers in countries like Ethiopia being nominal (Tsan et al., 2019). This is worsened by weak awareness and training on the new mobile and internet-based technologies and their potential towards agrarian change (Adebo, 2014; AGRA, 2015; Misaki et al., 2018). Therefore, fostering literacy and appropriate digital skills, especially among the youths, women and the elderly will be essential in keeping pace with the process of digital transformation and the building of digital societies (Misaki et al., 2018; Steinfield and Wyche, 2013; Trendov et al., 2019).

The high level of technological complexity is a barrier to the adoption and use of most existing mobile and web-based innovations. According to Featherman and Pavlou (2003) and Kotze, Anderson, and Summerfield (2016) besides acceptance and adoption processes, risk perceptions may strongly influence the individual's decision when dealing with complex technologies. Also, despite this being compounded by a lack of skills, old age, poor education, and language barriers, particularly in smallholder farming systems (Misaki et al., 2018; Trendov et al., 2019), innovations targeting farmers in that sector should be simple and tailored for their situations. For example, illiterate and older farmers can be supported by simple text-based innovations using local languages instead of sophisticated applications.

High costs of ICT devices such as mobile phones (smartphones), computers and costs of accessing network signal and the internet are fundamental barriers to the adoption and use of ICTs including mobile phones by various smallholder farmers (Krell et al., 2021; Misaki et al., 2018; Trendov et al., 2019). According to AGRA (2015), despite having access to mobile devices and services majority of the women and young people especially rural youth fail to meet the costs of maintaining the devices, buy airtime and data. However, Wyrzykowski (2020), reported that the average cost of mobile devices decreased from 57% of monthly income in 2015 to 30% in 2019 in SSA.

Unavailability and poor connectivity of both internet and mobile network services are additional barriers to the use of mobile technologies by smallholder farmers especially in remote areas (AGRA, 2015; Messenger, 2018; Trendov et al., 2019). Thus, the speed and quality of broadband services are generally poor in rural areas compared to urban areas in most developing countries (ITU, 2020; Steinfield and Wyche, 2013). Ultimately, these factors negatively impact the introduction and operationalisation of ICTs for supporting smallholder farming systems.

The costs of ICT-based and telecommunication equipment and technical infrastructure supplies such as satellite systems, servers, telecom towers, fibre optic cables, and voice over internet protocols (VoIP) especially in rural farming areas are a great concern to investors and developers (AGRA, 2015; Roy, 2009; Statista, 2020). Besides being costly, investments in such technologies are considered risky (World Bank, 2017), and hence their establishments seem uneconomical to them (AGRA, 2015). However, as argued by Roy (2009), it is possible to easily overestimate these costs and underestimate the cumulative benefits which can be brought by the technologies. In line with these factors, most farming communities lack digital infrastructure due to the investment costs associated with them. Despite the economic disruptions caused by the COVID-19 pandemic, GSMA (2020) expects major operators in the SSA region to have invested over USD50 billion in infrastructure rollouts between 2019 and 2025.

Availability of electricity especially in rural farming areas is unreliable and has broadly curtailed access to and use of ICT-based innovations in smallholder farming areas (Abebe and Cherinet, 2019; AGRA, 2015; Roy, 2009). This has not only impacted the introduction of new technologies in the areas but also on the everyday activities and businesses such as repairing and charging mobile phones (Abebe and Cherinet, 2019; Ogutu et al., 2014). Carefully planned Public-Private Partnerships (PPPs) can be effective instruments to support the expansion and availability of electricity and its distribution support infrastructure to previously underserved areas and communities (Ogutu et al., 2014; SNRD, 2016; Wyrzykowski, 2020). Furthermore, investments in solar energy as a cheaper and cleaner alternative should be supported to sustain the power supply in rural areas.

Cultural attitudes and social norms (e.g., gender norms) that characterise most parts of the smallholder farming communities in SSA often discriminate against women's access to technology (FAO, 2018). This is because, the current ICT-based technologies for supporting smallholder farmers lack services designed to meet the needs of women farmers (Batchelor et al., 2014). Also, it could be because women are generally perceived to be vulnerable to abuse from men when allowed to work with mobile phones (FAO, 2018). However, Kotze et al. (2016) note that women's limited adoption of high-tech products could be because they are less optimistic and have higher levels of risk aversion than men. Therefore, this generally implies that improving women's access to and use of mobile phones and the internet breaks some of these gendered barriers and can improve smallholder agricultural productivity since women are the majority producers in that sector (Zyl et al., 2014).

2.7 Application of mobile and web-based technologies to improve smallholder agricultural extension aervices : A critique of case studies in SSA

There are various agricultural Apps and web-based platforms being implemented to support agricultural extension delivery and transformation of smallholder farmers in SSA (Costopoulou et al., 2016; Daum et al., 2018; World Bank, 2017). Given the need to address heterogeneous and complex farm management issues within the smallholder sector (Consolata, 2017; Costopoulou et al., 2016), the “App economy” is constantly evolving and also becoming complex (ITU, 2020; Krone et al., 2016). This review identified five key applications being currently used to improve extension services delivery in SSA. These include Esoko, iCow, CKWs, WeFarm, and DigiFarm. Although this is by no means an exhaustive list, a review of these identified few innovations creates an awareness of their development, uses, impact and general limitations.

2.7.1 Esoko

Esoko is a technology platform focusing on bringing marketing information to farmers across Africa. It was established in 2005 in Ghana, and currently operating in 16 African countries including Nigeria, Sudan, Malawi, Kenya, Uganda, Rwanda, and Zimbabwe (AGRA, 2015). Its main objective is to empower smallholder farmers by making farming more profitable through access to agricultural information and markets (Van Schalkwyk et al., 2017). The initiative was initially designed to be a market intelligence tool for improving the availability of markets to smallholder farmers and businesses (Asare-kyei, 2013; David-West, 2010). However, within the first 5 years, it expanded into a wide-ranging platform extending its services to cover weather forecasting, crop production advice, and becoming an advertising platform for farmers and the agri-business community at large (AGRA, 2015; Qiang et al., 2012).

Some of Esoko's major activities involve the use of customised survey forms on mobile phones, tablets, or web-connected laptops to collect real-time data on market prices (farmgate, retail, or wholesale) and profile data for users (farmers, traders, transporters, and agents), which is constantly uploaded on the system (Asare-kyei, 2013). The enumerators as well as anyone can upload bids and offers to buy or sell agricultural products and services on the platform. The registered members are then categorised by location, commodity, and occupation and will receive automatic and personalised price alerts, buy and sell offers through text messages. Anyone can also upload offers using the online web and Esoko automatically sends the bids or offers via mobile phones whenever there is a match between a buyer and seller. Besides marketing services, the registered farmers periodically receive bulk SMS as reminders for farming activities or advice on certain farming practices and weather forecasts (Asare-kyei, 2013). The Esoko platform also has a call centre called "Helpline" where farmers can directly acquire expert advice (Van Schalkwyk et al., 2017).

In terms of its scalability, by 2017, the system was already serving more than 350 000 farmers in 10 countries across Africa (Van Schalkwyk et al., 2017). Until that year, approximately 9.5 million messages were collected from 70 markets and shared on the platform. Despite smallholder farmers being initially the main target clientele (GSMA, 2020), the Esoko platform has further expanded its services to target major agribusinesses, network operators, NGOs, and government ministries (Van Schalkwyk et al., 2017). In Zimbabwe, the Esoko mobile platform which started its operations in 2012 was servicing more than 17 fresh produce markets, covering 33 agricultural commodities, and supporting over 170 000 smallholder farmers across the country by the end of 2015 (Ifeoma and Hove, 2015).

One of the main challenges faced during the implementation of Esoko was that the existing content of market information could not be digitized and or commercialised. Thus, content collected from the field was largely inaccurate, stale and not accepted by farmers (Asare-kyei, 2013; Van Schalkwyk et al., 2017). Esoko developers had assumed that data from central sources like government publications were readily available and of good quality. They, however, addressed the challenge by creating their content of market information to meet the target market demand. Also, during their initial implementation process, developers noticed that instead of pushing content into the Esoko system as anticipated, more business was made by pulling out data from the system. This was data demanded by buyers and other service providers seeking to understand the needs, locations, and farming activities of farmers (GSMA, 2020). In addition, based on its initial development experience, Esoko realised later that most of its partners were inexperienced in farmer training and did not understand mobile phone technologies. This has resulted in them investing more money to create a consulting-like capacity from within to ensure its effective deployment and the training of farmers. However, in moving forward, the system is well-placed to continue fighting gender imbalance in its client base as it seeks to facilitate access to its services by more women farmers (www.esoko.com)

2.7.2 The Community Knowledge Worker (CKW)

The Community Knowledge Workers initiative was launched in 2009 in Uganda by Grameen Foundation to help in delivering agricultural and marketing information to smallholder farmers located in the rural areas of Eastern and Northern Uganda. Its main objective was to achieve impact at the farm level by providing rural advisory services to remotely located smallholder farmers through a combination of technology and human network (peer advisors) (a form of farmer-to-farmer extension) (Grameen Foundation, 2014; Van Campenhout, 2017). The system uses locally recruited farmers/villagers (referred to as CKWs) to further expand the reach of the government's rural advisory service workers (Van Campenhout, 2017).

The CKW system offers its services free of charge to farmers and relies on donor funding to support its activities. Agents of CKW work in partnership with other organisations known as service partners. The Uganda National Agro-Inputs Dealers' association is one of the partners providing information on input agri-suppliers across the country (Van Campenhout, 2017), while Makerere University and the National Agricultural Research Organisation (NARO), provides crop and livestock information (Amadu et al., 2015). In Kenya, where CKWs are known as Village Knowledge Workers they work in partnership with Farm Concern International, which is an organisation that focuses on market development and smallholder commercialisation organisation (Amadu et al., 2015).

In recruiting the CKW agents, community members with facilitation from Grameen Foundation nominate individuals from community farmers' groups based on key requirements, including education qualifications, leadership skills, residency in the community, trustworthiness, community respect, readiness to be early adopters of new ideas and willingness to devote some time per week to carry out extension work. Nominees are interviewed, and potential CKW agents are given Android smartphones, which are preloaded with an in-house developed mobile application (CKW App suite system) and then trained on how to use it (Grameen Foundation, 2014). In addition, the CKW agents, receive a bicycle, and solar power equipment on loan arrangements which assist them in delivering services. The CKW system uses three major applications namely, CKW Search, CKW Pulse, and CKW Survey (now called TaroWorks) (Amadu et al., 2015). The CKW Search comprises a searchable library where CKWs can check for agricultural, weather and marketing information requested by the farmers and feed into the central repository to target extension and marketing services providers (Qiang et al., 2012; Van Campenhout, 2017). The agents use the internet and the App to access information from the repository and convert it into contexts that are understandable to local farmers when delivering the messages (Amadu et al., 2015; McCole et al., 2014). The CKW Pulse allows agents to communicate directly with experts at the CKW headquarters to access monthly targets and monitor their progress. All data collection or surveys are, therefore, done using the TaroWorks app. The TaroWorks and CKW Search Apps can both operate online and offline allowing the agents to search for information or track farmer activities in areas without cell phone coverage. All information cached offline is later transmitted to a remote server called "Salesforce" when the CKW agent comes within cell phone network coverage (Amadu et al., 2015). All activities of CKW agents are supported by call centres operated by agricultural experts to address concerns raised by farmers (McCole et al., 2014).

The CKW system has since been replicated in many other African and Asian countries like Kenya, Ghana, India, China and Indonesia. In 2014, the CKW together with its partners had completed over 100 000 unique interviews and 1.5 million total interactions with over 300 000 of its registered farmers across the 43 districts in Uganda (Grameen Foundation, 2014). In Indonesia, the CKW programme, Ruma, reached over a million clients in 2014. Thus, Amadu et al. (2015) note that CKWs are creating a greater impact especially by serving remote areas "last mile principle" where poor road networks and infrastructure often discourage the government extension officers from visiting. Furthermore, one of the strengths of CKWs is that farmers do not necessarily need cell phones to receive agricultural information as the agents use their smartphones to acquire information and physically provide the information to farmers. The CKW agents are paid monthly, and incentives are also given to top achievers as a way of motivating them.

In a study by Van Campenhout (2017), to assess the impact of CKW on crops grown by beneficiary farmers in Uganda, results show that the presence of CKWs increased the percentage of farmers growing high-value cash crops such as coffee and beans. However, the intervention was found to have reduced the total number of farmers growing food crops such as millet, cassava, and sweet potatoes. This can be attributed to the improved access to marketing information for higher-value cash crops by the farmers. In the same study by Van Campenhout (2017), farmers who had access to the CKW system received prices that were on average 12–16% higher than those without access.

One of the main limitations of the CKW is that through the nomination process, the villagers might select popular members who lack the right motivation for smallholder agricultural information services delivery. Also, favoritism, jealousy, nepotism and community politics may influence the nomination process. Thus, agents could only be motivated to work on repaying smartphones and bicycles acquired on credit than providing better quality extension service to their peers (Amadu et al., 2015). In that regard, Grameen Foundation provides little remunerations and commissions to motivate its agents. Also, Misaki et al. (2018) note that lack of mutual understanding and commitment including diverging visions with partners caused tensions that limited the effective outreach and scalability of the initiative. For example, the CKW operations were terminated and forced to lay off in Massaka District, Uganda after the closure of one of their key partners (East Africa Dairy Development project) in 2013 (Amadu et al., 2015). In looking forward, the CKW considers the importance of using a fully blended multi-channel approach to improve the effectiveness of the extension services in reaching needy farmers.

2.7.3 iCow

The iCow is a comprehensive mobile phone-enabled agricultural information platform that was launched in 2011 in Nairobi, Kenya. Its main objective is to enable modern cow farming techniques, technological solutions and improved information to be disseminated to smallholder livestock producers who do not have access to large, and industrialized resources (Lexi, 2014). It is a mobile agricultural App that assists in improving access to good agricultural practices in real-time and upscale the smallholder livestock farmers in East Africa (www.icow.co.ke). The iCow App runs on a fee-for-service model with users being charged a premium rate-SMS for all services obtained through the system. It generates its income through a revenue-share model with Safaricom (mobile network company) and through third-party users interested in data, reports or having a presence in the content. The iCow's services are offered by Green Dream Technology (GDT) in partnership with Safaricom Foundation and International Livestock Research Institute (ILRI).

The App has been designed to work on both basic (features) and smartphones and can be accessed in multiple languages while covering various aspects of farming (Livestock, Crops and Soils) delivered through SMS and voice. The iCow system has many features and is always being constantly developed. ‘Mushauri' is a platform that provides education and advice to subscribed users (livestock farmers) by sending weekly 'tips' on husbandry practices and management. 'Kalenda' consist of calendars that are customisable to individual cows (Cow Kalenda), calves (Calf Kalenda), and heifers (Heifer Kalenda) for use by farmers in livestock management. "iCow Soko" is a marketplace for farmers to buy and sell the products they produce and those not available in agro-dealers. Potential buyers receive the contact numbers of sellers through the iCow platform. ‘Vetenari’ provides access to a database of registered vets and support services. The iCow platform, therefore, effectively performs as a virtual veterinary nurse, midwife, and farm management consultant, providing information to the farmers on cow gestation, milk production as well as health and nutrition (Lexi, 2014). Farmers registered for the service can create profiles or register their animals by capturing key data about individual cows, including insemination dates and anticipated calving dates. Such data will be used by experts in developing tailored information and timely reminders for all important husbandry practices and sent to the farmers every week (Marwa et al., 2020).

The iCow App has been replicated in Tanzania and Ethiopia in 2016. At inception in Kenya, it had only 4000 farmers but has increased to over 580 000 users since 2011 (CTA, 2017). Some farmers who started using iCow since its launch in 2011 have reported some substantial benefits including a 51-75% increase in their overall efficiency (Lexi, 2014). For example, one of the farmers reported significant increases in milk yields of up to 30 litres from the previous 15 litres as well as improvement in the general health of the animals (Lexi, 2014). Also, farmers using Mashauri and those who had stayed on the platform for longer periods reported reduced veterinary costs, diseases and calf mortality incidences. According to Marwa et al. (2020), iCow services in Kenya have increased annual milk production per cow, income from milk sales, and household income by 13%, 29%, and 22%, respectively.

The iCow’s main limitation was a lack of awareness. In a study conducted by Dolan and Burns (2014), the iCow App was reported to be unknown to dairy cooperative farmers located within a four-hour radius of the company's base in Nairobi.

2.7.4 WeFarm

WeFarm is a farmer-to-farmer digital network and social enterprise founded in 2015 in Kenya. Its major aim is to connect smallholder farmers across the region in solving challenges, sharing ideas, and spreading innovation. Thus, users can share information irrespective of their type of agricultural enterprise, location, language, or place across the value chain (Ellie, 2015; Henze and Ulrichs, 2016). Its services can be offered without having to travel or spend money and most services can be accessed by the farmers without an internet connection. Thus, WeFarm's key novelty is the creation of the region's first crowdsourced peer-to-peer farmer network especially for communities without internet access. The system's SMS service App enables farmers to present questions through free SMS shortcodes and receive crowd-sourced responses from other registered users (Henze and Ulrichs, 2016; Trendov et al., 2019). WeFarm uses the internet to process messages through a series of custom-built machine learning applications and share with other users to respond and provide answers (Ellie, 2015). Every message is categorized with many tags that define its intent, language used and content, and in that process, the system picks the best-matched responses or answers and relays them back to the farmer as SMSs. Currently, users can communicate in three main African languages; Kiswahili, Luganda, and Runyankore, which are used in addition to English (WeFarm, 2018). Farmers also use the platform to access agricultural inputs like seeds and fertilizer and non-agricultural products including cooking stoves, solar panels, and mobile phones (Mackay, 2019).

The WeFarm platform reached over 2 million users across Kenya, Uganda, and Tanzania by 2018 (Mackay, 2019). WeFarm is reported to have helped small-scale farmers improve productivity, gain insight into prices, able to fight impacts of climate change, access agricultural inputs, and diversify their farming interests. With one in five farms in Uganda and Kenya being able to use the WeFarm network, in a single calendar month in 2018, farmers managed to ask and answer over one million questions (WeFarm, 2018). According to Mackay (2019), the system achieved 1USD million in sales in the first few months of launching its marketing place.

One of the major limitations of WeFarm is its limited curation given that it works at a regional scale with farmers from very diverse ecological and socio-political farming environments. Thus, despite being able to break the language barrier and its ability to use machine learning tools to select the best crowd-sourced answers, its ability to moderate farmer-to-farmer skills exchanges and select appropriate responses is questionable. Also, despite allowing farmers to present their questions for others to provide advice, the system does not offer direct interactivity among farmers including ongoing discussions and probing for better explanations. Thus, it practically simulates an end-to-end information exchange which is more silo-based as the content receiver does not know exactly where the solution came from (FAO, 2017).

2.7.5 DigiFarm

DigiFarm is an integrated mobile-based system developed to offer convenient, and one-stop access to a diversity of digital services tailored for smallholder farmers (SVAI, 2018). In 2016, Safaricom partnered with Mezzanine to establish the DigiFarm platform which was launched in 2017 in Kenya. The initiative's objectives were to create statistical data on farms and farming activities conducted in Kenya, create a farmers' marketing platform, and improve access to extension services, and financial services by the farmers (Shrader et al., 2019). Since Safaricom lacked expertise in delivering all services, DigiFarm draws on a wide range of skills from many other partners including, iProcure (providing inputs), FarmDrive (managing the loan book), Arifu (providing learning content/modules) and iShamba (providing digital and video learning content) (Denyes et al., 2018). Besides many services it provides, DigiFarm, also, serves as a national database that captures statistical data of all farms and farming activities in Kenya. This data is expected to assist in long-term planning and the provisioning of customised solutions to the farmers. In addition, smallholder farmers are using DigiFarm's loan module to apply for small loans particularly for buying production inputs such as livestock feed and can pay via a mobile bank account and payment App (M-Pesa) (SVAI, 2018).

DigiFarm is a text-based platform that is accessible using either basic feature phones or smartphones and farmers do not pay for the service. Farmers can register or sign up to the platform by capturing details about their farms and farming activities or they can register through agents such as Kenya Livestock Producers Association (KLPA). All users registered on the platform, have access to a suite of products and services that the ecosystem offers. These include extension services via learning modules, electronic vouchers for buying inputs, training on different farming activities, and general advice on agriculture and animal husbandry practices.

When DigiFarm was launched, it registered more than 700 000 farmers in the first year with a 35% active rate and as of May 2019, the platform was hosting more than one million registered farmers and expecting to reach 5 million users in 2023 (Denyes et al., 2018). In 2018, nearly 310 000 smallholder farmers accessed DigiFarm's educational content through its learning partners such as Arifu with more than 2 million interactions on the service (Shrader et al., 2019). The system continues to evolve with new sub-Apps being introduced, including DigiSoko, an open marketplace for agricultural produce (Shrader et al., 2019). Currently, government agents, input providers, financial institutions, and other agri-service providers can network with and reach out to smallholder farmers with agricultural-related services. Over 50 000 farmers purchased inputs through iProcure in 2018 and many of the users were repeat customers (Shrader et al., 2019).

DigiFarm's limitations include lack of direct promotion and real-time farmer-to-farmer learning or interactivity for skills and innovation exchange. Therefore, it does not guarantee the provision of localised extension solutions to farmers. Another limitation is the very low participation by women on the platform (Denyes et al., 2018). In trying to address this challenge, DigiFarm has engaged KLPA, and other registration point service providers to ensure a more effective way of engaging with women and improving its system functionally to remove any aspects that might discourage women participation.

2.8 General limitations and prospects of improving the existing-ICT-enabled initiatives used in agricultural extension services in SSA

Generally, the involvement of farmers (end users) in the development process of many of the above-mentioned ICT-enabled initiatives is limited. Although the initiatives do address some pertinent farmer constraints and challenges, they are being created without substantive research-based needs assessment information (Tsan et al., 2019). Limited farmer involvement in the initial phase of inventing digital technologies for use in agriculture has been described by World Bank (2017) and Misaki et al. (2018) as a common issue in many developing countries. However, for the technologies to generate demonstrable value, they must be created based on the multidimensional needs and experiences of the end-users (Dolan & Burns, 2014; Emeana et al., 2020; Konaté et al., 2020). A study by (Henze and Ulrichs, 2016) in Kenya suggested that end-user involvement in the development process can enhance the applicability and usefulness of the interventions. Primarily, it can boost user trust, and this often allows the innovation to continue even after donors have pulled out (Zyl et al., 2014). A lack of preliminary market research caused the deployment framework of Esoko system to be changed on two separate occasions as it failed to meet the needs of the users (David-West, 2010). This is because not involving users will cause them to perceive the newly introduced technology as a foreign tool or forced innovation (Costopoulou et al., 2016) and this later affects adoption. A previous study on mobile Apps for agriculture by (Costopoulou et al., 2016) also in the global mobile ecosystem showed that the mobile agricultural Apps had a low rating in stores' related tags indicating that they did not meet needs of agricultural stakeholders.

Baseline surveys are fundamental and should be a component of the development processes of innovations including digital-based agricultural solutions or supporting smallholder farmers. While this may sound to be apparent, a review of the existing technologies shows that many developers overlook this step. According to Tsan et al. (2019), such innovations, therefore, lack rigor and robustness because they do not have baseline data and indicators to enact their continuous monitoring, evaluation, and future improvements. Consequently, impact metrics for most of the innovations developed without baseline information are inaccurate and unreliable because they will be largely based on hypothetical and anecdotal evidence (World Bank, 2017). A study by Ochieng et al. (2014) acknowledged the presents of several challenges in assessing the impact of ICT-based market information services on smallholders' farm input use and productivity in Kenya.

Based on this review, it can also be deduced that the creation of extension content and its dissemination within the current initiatives is not farmer-driven (Tsan et al., 2019). While farmers can present questions to agricultural experts and fellow farmers for advice through the technologies such as WeFarm, CKW, iCow, DigiFarm, and Esoko, direct and real-time farmer-to-farmer learning or interactivity for skills and innovation exchange is not provisioned. According to Nakasone et al. (2013) and Costopoulou et al. (2016), in developing countries and the global ecosystem, most existing mobile and web-based innovations simulate principal-agent linear-based models just like conventional extension systems. Thus, solutions linearly flow from experts to farmers, which makes the farmers just content receivers of the pre-determined agricultural information and services (World Bank, 2017). Anjum (2015) reported that most farmers experienced problems with the Mobile Multimedia Agricultural Advisory System (MAAS) in India due to the limited knowledge of agricultural experts at the call centre. The farmers were receiving poor-quality information, which was untimely, inaccurate and unreliable. However, interactive and participatory innovations and approaches can generate significant opportunities for multi-directional information sharing leading to demonstrable impacts for the smallholder farmers and these are encouraged (World Bank, 2017). They allow farmers, to work with content that is validated by them and shared by their peers, which influences the generation of customised information, services, and inputs that suits their needs (Konaté et al., 2020). A recent study by Krell et al. (2020) in central Kenya demonstrates the importance of linkages between ICT adoption rates and the role of informal and formal farmer groups. Thus, farmer groups allow farmers to co-create, process and share information about their own experiences among themselves with extension officers and researchers being facilitators and not teachers (Franzel et al., 2015). This, also, presents new prospects for documentation of farmer-driven innovations which define traditional knowledge (World Bank, 2017).

Generalizability at the farm and community farming system levels seems to be limited across the existing mobile-enabled agricultural applications. The findings of Anadozie et al. (2021) in North-East Nigeria indicates that most of the ICT-based initiatives targets a few isolated farm enterprises or specific objectives of interest rather than accounting for the whole farm system holistically. However, system-based perspectives emphasize the need to view a farm or farming community as a whole and not as separate strata (Magoro and Hlungwani, 2014). As such, platforms such as Esoko which aimed to provide farmers with only a narrow stream of market information ended up facing scalability challenges (AGRA, 2015; GSMA, 2013). This is because what it initially offered became incompatible with demands coming from developing markets which required a broader coverage of various agricultural products and services (Van Schalkwyk et al., 2017). According to Marwa et al. (2020), the iCow platform which started as a virtual veterinary nurse only for dairy cows also lacked generalizability since it was not covering other classes of cattle such as beef animals and important activities such as forage production, milk processing, and marketing.

This study has similar observations to Costopoulou et al. (2016), who reported that many agricultural Apps for smallholder farmers were being designed and developed without adequate input from other key stakeholders, including research institutions and government extension departments. Therefore, Garforth and Lawrence (1997) posited that such innovations often fail to meet the needs and requirements of the targeted users. For example, most of the new technologies are being developed in isolation (SNRD, 2016) and are running as parallel models to the existing public extension model. However, a public extension system is a fundamental source of information, and promoter of technology adoption by farmers, and a bridge to the farmer-research linkage (Ali, 2012; Mapiye et al., 2019; SNRD, 2016). Thus, the new technologies require public agencies' active involvement, especially the extension officers (Costopoulou et al., 2016; Karanja et al., 2020; Mabe and Oladele, 2015). It also requires strategic private partners to improve its sustainability. This is despite partners like most mobile network organisations want exclusivity and to support manly those Apps that are already operating at scale (Batchelor et al., 2014; Qiang et al., 2012). Zyl et al. (2014) argued that adequate collaboration with various other strong institutions is important because it increases the trust (Misaki et al., 2018) of farmers to work with the innovations. Therefore, as suggested by Danes et al. (2014), the technology developers need to build on the existing networks of government extension, fellow farmers, known traders, research institutions, NGOs, private companies, and local consultants.

Another key limitation is that most smallholder farmers, especially the resource-constrained have low incomes hence are unable and or unwilling to pay for the use of mobile and web-based technologies (Krell et al., 2021; Qiang et al., 2012). Thus, Kaur and Kaur (2018) argued that many deployed technologies have often failed to scale up not because of their irrelevance, but because of the failure by farmers to pay for accessing them. For example, efforts to establish digital extension systems, such as iCow and RML Agtech in India through selling subscriptions to farmers resulted in the technologies reaching only a small fraction of the targeted users (Tsan et al., 2019). Thus, according to Qiang et al. (2012) report on mobile applications for agriculture and rural development, only 29 percent of the applications studied had sufficient revenue streams to cover operating costs. A lack of sustainable revenue streams ultimately affects the continuity of these technologies, especially after the donors withdraw their funding. Although it has been proven that low-income people are sometimes willing to pay small fees for innovations they believe will meet their needs (Drafor, 2016), the main challenge for developers is to convince farmers that their systems add value to farming and meeting that promise. Besides the issues of making the innovations affordable, the other challenge facing existing developers is how to make them accessible in venues and forms that are convenient to smallholder farmers (Dlamini and Worth, 2019). Therefore, to ensure better affordability and accessibility of the innovations, especially by smallholders who may not afford to pay full-service fees, the development and implementation programmes require strong partnerships and extensive awareness campaigns with various key stakeholders participating (Zyl et al., 2014). Also, the farmers who are unable to meet the costs of acquiring smartphones and their advanced applications should be allowed to access innovations through alternative means (Ali, 2012) such as interventions designed to work with basic phones (Krell et al., 2021).

Apart from low income, many studies have indicated that lack of education and digital skills are also key factors that impede opportunities for the farmers to access relevant and timely agricultural information and services (Henze and Ulrichs, 2016; Misaki et al., 2018; Anjum, 2015; Dlamini and Worth, 2019). Some of these essential skills which farmers lack include the ability to register themselves and access the applications, update their profiles, and use various methods such as SMS, picture, audio, and voice to communicate Anjum (2015). In a study by Rashid and Laurant (2014), on International Development Research Centre (IDRC) supported projects in Canada, more than 90% of the farmers on the DrumNet App technology were not able to send an SMS for business purposes due to illiteracy. The effects of illiteracy and digital illiteracy among smallholders are being worsened by a lack of training and awareness campaigns about the innovations especially during the development and deployment phases (Danes et al., 2014; Dlamini and Worth, 2019). A study by Anjum (2015) in Bangladesh, found that almost all the farmers (99%) were not aware of a web-based agricultural market information system that was initiated and sponsored by the government implying a failure by the government to promote the system. Therefore, end-user training and awareness campaigns are critical in improving the adoption and usefulness of the applications (Abebe and Cherinet, 2019; Adebo, 2014). Besides the farmers, the extension officers and all targeted services providers working with farmers also require training and re-training to improve their skills and awareness (Mabe and Oladele, 2015). However as argued by Henze and Ulrichs (2016), this could attract a huge cost factor especially for start-up technologies with limited funding.

Based on the review findings, the issue of gender imbalance remains a big challenge to the scaling and sustainability of the existing Apps. Innovations like Esoko and CKW struggled to close the gender gap and are introducing programmes that mainstream the inclusion of women. Also, the studies by Zyl et al. (2014) and Dlamini and Worth (2019), in Africa reported that far much fewer women compared to men had access to mobile and web-based technologies. In trying to address the gender imbalance some programmes such as the Up-scaling Technology in Agriculture through Knowledge and Extension (UPTAKE) in Tanzania which aimed to achieve 50% representation in its database have failed to reduce the gap (Karanja et al., 2020). Of the 55,710 farmers recruited for the programme, 73% were men while 27% women. This suggests the need for more strategies in improving the uptake of mobile and web-based technologies by women farmers and other vulnerable groups like youths and the elderly (AGRA, 2015; Karanja et al., 2020).

Scalability is one of the challenges which agricultural App developers face. The ability to build initiatives or systems that are self-sustaining beyond their initial grant funding periods is one primary factor compounding the problem of scalability (Grameen Foundation, 2014; McCole et al., 2014; Zyl et al., 2014). However, the report by Qiang et al. (2012) shows that over 50% of the mobile agriculture Apps studied globally achieved scalability during stage one of their development. In this review, the experience by Esoko shows that, despite the initiative demonstrably achieved better impacts, it could not immediately replicate itself virally because of the higher costs it incurred in bringing in new clients (GSMA, 2013). Esoko's overall deployment costs constituted 95% of the total costs incurred in building the technology (Van Schalkwyk et al., 2017). However, Henze and Ulrichs (2016) argue that despite being offered a lot of funding during design and piloting, most new technologies perform poorly during their marketing and in-field deployment. Thus, the technical capacity of the innovations often fails even after the customer base is increased mainly because the developers underestimate the importance of marketing and capacity building of the technologies to various end-users before implementation (Danes et al., 2014). A group of USAID researchers discovered that the iCow platform, five years after its launch was unknown to cooperative dairy farmers within a four-hour radius of its base in Nairobi (Dolan and Burns, 2014).

2.9 The proposed intervention : A Livestock Management Database System

Smallholder farmers can benefit from innovative and far-reaching measures to overhaul extension services. Thus, a revitalized extension system can promote the sustainability of farmers and local development through the provision of tailored services stimulating collective among the farmers (Burch, 2007; Davis & Terblanche, 2016). The LMDS technology aims to help commercially oriented smallholder farmers become sustainable and achieve growth by providing timeous and relevant information and extension services. The need to develop the innovation was driven by evidence obtained from literature review showing the inefficiency of public extension systems (Duvel, 2000; Worth; 2006; Akpalu, 2013; Mapiye, 2019) and limitations of the existing ICT-based solutions in supporting smallholder farmers.

The system is designed into a customizable and easy-to-use mobile application and web-based suite accessible through mobile phones, tablets, or computers. Figure 2.3 presents the schematic representation of the LMDS and how it will connect farmers with extension and various agri-value chain players. The tool will initially focus on two operational levels; farmers and the DALRRD, while researchers and other value chain actors will be added to provide services to farmers as the system scales. It is designed to facilitate peer-to-peer information exchange with extension officers providing moderation and curation services on the platform. The shared information recorded in the LMDS database becomes a repository of the farmers' indigenous technical knowledge. Organizing this information and storing it in a database could be convenient to make it accessible to farmers, extension officers, and researchers who might need to test the information. This presents new prospects for farmer-led documentation of local innovations which define traditional knowledge (World Bank, 2017).

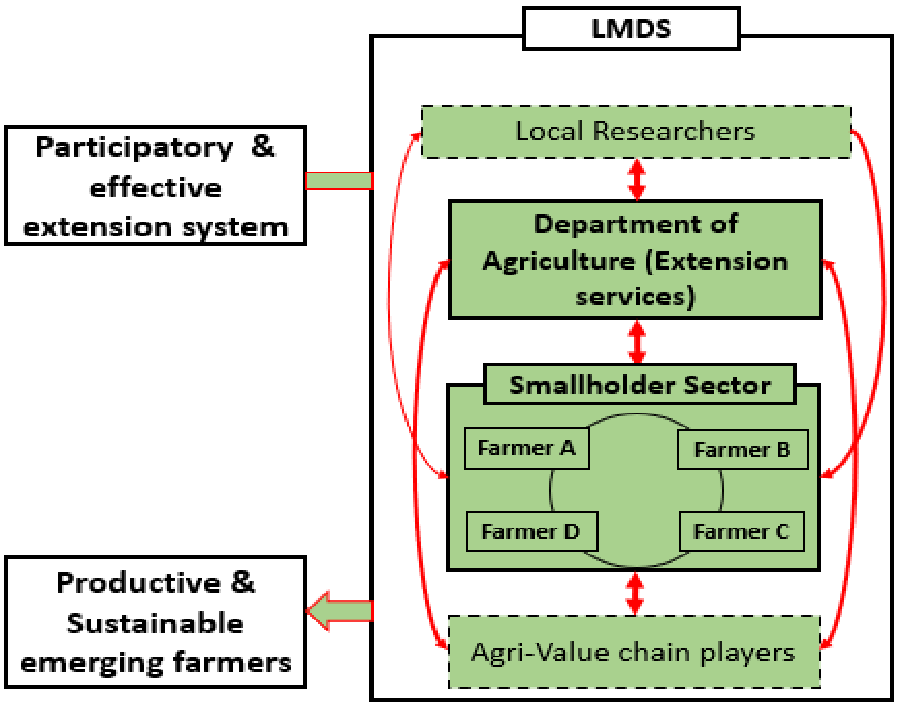

Figure 2. 3 Schematic representation of the LMDS showing the customer segments and how they will be interlinked for a productive farming system

The LMDS is developed from an understanding of the specific needs and preferences of the targeted users, who are farmers and opinions from agricultural extension officers. This makes it an immersive and user-centric intervention capable of meeting the targeted users' expectations (Asare-Kyei, 2013; CTA, 2019). It is important to involve end-users directly in developing new agricultural innovations since this increases trust among them, resulting in the innovation being less reliant on donor funding (Zyl et al., 2014).

An important feature that differentiates the LMDS from many similar interventions is the creation of its baseline conditions. The baseline conditions will be used for future impact assessments and improvements of the innovation to ensure it maintains its intended goal of improving the sustainability of commercially oriented smallholder farmers. This ultimately promotes rigor and robustness of the intervention (CTA, 2019).

Public extension systems remain fundamental sources of information, promoters of technology adoption and bridges to the farmer-research linkage in smallholder agricultural systems (SNRD, 2016; Mapiye et al., 2019). However, most of the new ICT-based initiatives for farmers are being developed in isolation (SNRD, 2016) and operating as parallel extension models to the existing public extension approaches. These new technologies require the active involvement of public agencies, especially extension officers, to effectively meet the needs of the farmers (Costopoulou et al., 2016). For instance, partnering with the DALRRD will help harness more trust, cooperation, and acceptance of the technology by the farmers because farmers have always relied on the government for new technologies. Therefore, it is important to note that the LMDS model is not being introduced as a substitute to the current public extension approach (technology transfer-based) but rather as a complementary initiative.

Developing such ICT-based initiatives for delivering extension services is often faced with scalability and sustainability challenges (Burch, 2007; Batchelor et al., 2014; World Bank, 2017). According to Emeana et al. (2020), the aim of achieving scale often appears ambiguous for many development practitioners of these innovations. Therefore, the proposed LMDS intervention must move beyond the pilot stage and be adopted by the targeted farmers and the government. The ability and willingness of users to pay for the system could indicate the potential for scalability and sustainability. However, some farmers in the commercially oriented smallholder sector may not afford to pay full fees to access the system (Zyl et al., 2014). In that regard, tiered payment systems could be implemented, such as cost-sharing arrangements between the government and the farmers or farmers organizations (SNRD, 2016). Through awareness campaigns, the farmers can also be educated on the importance of accessing information and services that can leverage their sustainability. A case study to elicit farmers' willingness to for a proposed new intervention could provide insights into the preparedness of farmers to support the innovation. Thus, a higher likelihood of farmers paying for new technologies guarantees the sustainability of the innovations. Also, understanding user attitudes or perceptions of the innovation before its development is important as positive perceptions are a proxy of new technology adoption (Meijer et al., 2015; Alomia-Hinojosa et al., 2018; Massresha et al., 2021).

2.10 Conclusion

Smallholder farmers are essential players in achieving food security and poverty reduction in SSA. Despite the many ecological, economic, and institutional challenges constraining them, their primary challenge is limited access to relevant and timely agricultural information and services. Lack of access to relevant information and services affects their ability to address daily challenges and respond to opportunities. However, the penetration and propagation of mobile phones, the internet, and growth in mobile network coverage across the region have led to a surge in mobile services for rural smallholder agricultural systems. In response to this ICT revolution, currently, there are dozens of mobile and web-based agricultural technologies trying to promote access to agricultural information and services by smallholder farmers. Many of them are being implemented in Eastern and Central Africa implying a huge gap for Southern Africa. Most of the services are being offered through basic feature phones using SMS and voice, especially towards resource-poor households. However, with smartphones' current penetration and adoption rate across the region (over 50%), focusing on their use could bring more positive impacts. This is because they allow audio, video, and picture messages to be shared and are compatible with improved Apps and connections to 4G and 5G networks, giving a much faster and better browsing experience.

Many positive developments and promising impact metrics are emerging from applying the various initiatives in supporting smallholders. These include market linkages, access to production and weather information, and mobile banking services. However, most of the technologies have remained limited. Information and services dissemination still portray a linear and principal-agent arrangement where farmers receive pre-determined information and services. End-users of the technologies are not included in the whole development process, which affects the adoption, scalability, and replicability of the technologies. Limitations such as illiteracy and digital illiteracy, language barrier, lack of strategic partnerships, gender disparities, and poor training and awareness campaign continue to hamper the development and sustainability of the initiatives. To improve adoption of the innovations and ensure optimal productivity of smallholders through better access to information and services, it is important to address the identified challenges and promote Private-Public-Partnerships to ensure availability of funding, implementation of customised training and awareness programmes targeting the smallholder farmers. Therefore, the review findings provide useful directions to the researchers, governments, and developers of mobile phone-based systems in developing sustainable ICT-based technologies for smallholder farming systems.

2.11 References

Abebe A and Cherinet YM (2019) Factors Affecting the Use of Information and Communication Technologies for Cereal Marketing in Ethiopia. *Journal of Agricultural & Food Information* 20(1). Taylor & Francis: 59–70. DOI: 10.1080/10496505.2018.1438290.

Adebo GM (2014) Effectiveness of E-Wallet Practice in Grassroots Agricultural Services Delivery in Nigeria – A Case Study of Kwara State Growth Enhancement Support Scheme. *Journal of Experimental Biology and Agricultural Sciences* 2(4): 411–418. DOI: https://doi.org/10.1080/15427528.2018.1496216.

AGRA (2015) *Africa Agriculture Status Report 2015. Youth in Agriculture in Sub-Saharan Africa*. Alliance for a Green Revolution in Africa (AGRA), Nairobi. Available at: http://www.agra.org/media-centre/news/africa-agriculture-status-report--2015-/.

Aker J and Mbiti I (2010) Mobile Phones and Economic Development in Africa. *Journal of Development Studies* 24(3): 207–232. DOI: 10.1080/00220388.2012.709615.

Akpalu DA (2013) Agriculture Extension Services Delivery in a Semi-Arid Rural area in South Africa: The Case Study of Thorndale in the Limpopo Province. *African Journal of Food, Agriculture, Nutrition and Development* 13(4). Available at: https://www.ajol.info/index.php/ajfand/article/view/94600.

Ali J (2012) Factors Affecting the Adoption of Information and Communication Technologies (ICTs) for Farming Decisions. *Journal of Agricultural & Food Information* 13(1): 78–96. DOI: 10.1080/10496505.2012.636980.

Amadu FO, McNamara PE, Davis K, et al. (2015) *Community Knowledge Workers for Rural Advisory Services*. 14. Available at: http://www.betterextension.org.

Amer J, Odero D and Kwake A (2018) Towards Improving Agricultural Marketing Information Systems for Smallholder Farmers: A Tharaka Nithi Case. *Journal of Agriculture and Sustainability* 11(2): 99–128.

Anadozie C, Fonkam M, Cleron J-P, et al. (2021) The impact of mobile phone use on farmers ' livelihoods in post-insurgency Northeast Nigeria. *Information Development* 37(1): 6–20. DOI: 10.1177/0266666919886904.

Anjum R (2015) *Design of mobile phone services to support farmers in developing countries*. University of Eastern Finland.

Asare-kyei D (2013) *Mobile Agriculture : Providing Tools and Support for Market Information Services and Commodity Price Exchange*. Geneva. Available at: https://unctad.org/system/files/non-official-document/SUC_GCF2013_18-03-2013_Daniel-ASARE-KYEI.pdf.

Batchelor S, Scott N, Manfre C, et al. (2014) Is there a role for mobiles to support sustainable agriculture in Africa? In: *ICT for Sustainability 2014, ICT4S 2014*, Stockholm, 2014, pp. 272–280. DOI: 10.2991/ict4s-14.2014.33.

Chingala G, Raffrenato E, Dzama K, et al. (2017) Towards a Regional Beef Carcass Classification System for Southern Africa. *South African Journal of Animal Sciences* 47(4): 408–423. DOI: 10.4314/dsajas.v47i4.1.

Consolata A (2017) Role of ICTS in accessing and disseminating information for improved urban livestock keeping in Tanzania. A review of related literature. *Library Philosophy and Practice (e-journal)* (1): 1502. Available at: http://digitalcommons.unl.edu/libphilprac/1502?utm_source=digitalcommons.unl.edu%2Flibphilprac%2F1502&utm_medium=PDF&utm_campaign=PDFCoverPages.

Costopoulou C, Ntaliani M and Karetsos S (2016) Studying Mobile Apps for Agriculture. *IOSR Journal of Mobile Computing & Application* 3(6): 1–6. DOI: 10.9790/0050-03064449.

CTA (2017) A Farmer Centric Mobile App. Technical Centre for Agricultural and Rural Cooperation (CTA), Available at: https://www.cta.int/fr/article/a-farmer-centric-mobile-app-sid04085fa31-6f26-40be-a46c-986b049be6e4 (accessed 31 March 2021).

Danes MHGI, Jellema A, Janssen SJC, et al. (2014) *Mobiles for Agricultural Development: Exploring trends, challenges and policy options for the Dutch government*. Alterra. Available at: http://edepot.wur.nl/297683.

Danso-Abbeam G, Ehiakpor DS and Aidoo R (2018) Agricultural Extension and its Effects on Farm Productivity and Income: Insight from Northern Ghana. *Agriculture and Food Security* 7(1). BioMed Central: 1–10. DOI: 10.1186/s40066-018-0225-x.

Daum T, Buchwald H, Gerlicher A, et al. (2018) Smartphone apps as a new method to collect data on smallholder farming systems in the digital age : A case study from Zambia. *Computers and Electronics in Agriculture* 153. Elsevier: 144–150. DOI: 10.1016/j.compag.2018.08.017.

David-West O (2010) *Esoko Networks : Facilitating Agriculture Through Technology*. *UNDP*. New York. Available at: http://growinginclusivemarkets.com/media/cases/Ghana_Esoko_2010.pdf.

Deichmann U, Goyal A and Mishra D (2016) *Will Digital Technologies Transform Agriculture in Developing Countries?* 7669. DOI: 10.1111/agec.12300.

Denyes L, Lesher N, Martinez M, et al. (2018) *Handbook: Digital Financial Services for Agriculture*. Johannesburg: International Finance Corporation. Available at: https://www.ifc.org/wps/wcm/connect/region__ext_content/ifc_external_corporate_site/sub-saharan+africa/resources/dfs-agriculture.

Dlamini MM and Worth S (2019) The Potential and Challenges of Using ICT as a Vehicle for Rural Communication as Characterised by Smallholder Farmers. *Asian Journal of Agricultural Extension, Economics & Sociology* 34(3): 1–10. DOI: 10.9734/ajaees/2019/v34i330202.

Dolan J and Burns C (2014) Beyond M-Pesa, Kenya's market slow to scale mobile solutions. *Devex*. Washington DC: Devex. Available at: https://www.devex.com/news/beyond-m-pesa-kenya-s-market-slow-to-scale-mobile-solutions-82618.

Drafor I (2016) Access to Information for Farm-Level Decision-Making. *Journal of Agricultural & Food Information* 17(4). Taylor & Francis: 230–245. DOI: 10.1080/10496505.2016.1213170.

Ellie A (2015) WeFarm: Connecting Small-Scale Farmers.

Emeana EM, Trenchard L and Dehnen-Schmutz K (2020) The revolution of mobile phone-enabled services for agricultural development (m-Agri services) in Africa: The challenges for sustainability. *Sustainability* 12(1): 485–490. DOI: 10.3390/su12020485.

Fan S and Rue C (2020) The Role of Smallholder Farms in a Changing World. In: Paloma SG y, Riesgo L, and Louhichi K (eds) *The Role of Smallholder Farms in Food and Nutrition Security*. Thiverval-Grignon: Springer, pp. 13–28. DOI: https://doi.org/10.1007/978-3-030-42148-9.

FAO (2017) *Information and Communication Technology (ICT) in Agriculture: A Report to the G20 Agricultural Deputies*. Rome: Food and Agriculture Organisation (FAO). Available at: www.fao.org/publications.

FAO (2018) *Gender and ICTs: Mainstreaming Gender in the Use of Information and Communication Technologies (ICTs) For Agriculture and Rural Development*. Rome: Food and Agriculture Organisation (FAO). Available at: https://www.fao.org/documents/card/en/c/I8670EN/.

Featherman MS and Pavlou PA (2003) Predicting e-services adoption: A perceived risk facets perspective. *International Journal of Human Computer Studies* 59(4): 451–474. DOI: 10.1016/S1071-5819(03)00111-3.

Franzel S, Degrande A, Kiptot E, et al. (2015) *Farmer-to-Farmer Extension*. 7. Lindau.

Garforth C and Lawrence A (1997) Supporting Sustainable Agriculture through Extension in Asia. *Natural Perspectives* (21): 1–10.

GIZ (2018) *Harnessing the chances of digitalisation for rural development: Lessons learnt from German-funded rural development projects*. Germany Corporation for International Cooperation-GmbH (GIZ), Bonn. Available at: https://www.nachhaltige-agrarlieferketten.org/fileadmin/media/Studien/GIZ_Harnessing_the_chances_of_digitalisation_for_rural_development_2018.pdf.

Grameen Foundation (2014) *Community Knowledge Worker: Uganda Program- Lessons Learned 2009-2014*. Washungton DC. Available at: https://grameenfoundation.org/partners/resources/lessons-learned-2009-2014-community-knowledge-worker-uganda-program.

GSMA (2013) *Esoko Case Study*. *GSMA - Mobile and Development Intelligence*. Global Systems for Mobile Connections (GSMA), London. Available at: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2016/02/Case_Study_-Esoko.pdf.

GSMA (2019) *Mobile Internet Connectivity 2019: Sub-Saharan Africa Factsheet*. Global Systems for Mobile Connections (GSMA), Nairobi. Available at: www.mobileconnectivityindex.com.

GSMA (2020) *The mobile Economy: Sub-Saharan Africa 2020*. Global Systems for Mobile Connections (GSMA), United Kingdom. Available at: https://www.gsma.com/mobileeconomy/wp-content/uploads/2020/09/GSMA_MobileEconomy2020_SSA_Eng.pdf.

Henze J and Ulrichs C (2016) The potential and limitations of mobile-learning and other services in the agriculture sector of Kenya using phone applications. In Proceedings of the 12th European International Farming Systems Association (IFSA) Symposium, Social and Technological Trans. In: Shropshire, UK, 2016, pp. 1–11. International Farming Systems Association (IFSA). Available at: https://www.harper-adams.ac.uk/events/ifsa/papers/2/2.5 Henze.pdf.

Hopestone KC (2014) The Role of ICTs in Agricultural Production in Africa. *Journal of Development and Agricultural Economics* 6(7): 279–289. DOI: 10.5897/jdae2013.0517.

ICASA (2020) *The state of the ICT sector in South Africa 2020*. Independent Communications Authority of South Africa (ICASA), Johannesburg. Available at: https://www.icasa.org.za/uploads/files/State-of-the-ICT-Sector-Report-March-2020.pdf.

Ifeoma OD and Hove M (2015) An Analysis of the Impact of the Use of Mobile Communica tion Technologies by Impact of the Use of Mobile Communication Technologies by Farmers in Zimbabwe. A Case Study of Esoko and EcoFarmer Platforms. In: *Conversations on Development: can ICTs make a difference in Climate, Political and Health Disturbances?*, Munster, 2015, pp. 1–25.

Isaya EL, Agunga R and Camilius AS (2018) Sources of agricultural information for women farmers in Tanzania. *Information Development* 34(1): 77–89. DOI: 10.1177/0266666916675016.

Isenberg S (2019) *Investing in information and communication technologies to reach gender equality and empower rural women*. Rome. Available at: https://www.fao.org/3/ca4182en/ca4182en.pdf.

ITU (2014) *Digital Opportunities: Innovative ICT Solutions for Youth Employment*. International Telecommunication Union (ITU), Geneva. Available at: http://girlsinict.org/sites/default/files/pages/youthreport_2014.pdf.

ITU (2020) *Measuring digital development: Facts and figures 2020. ITU Publications*. International Telecommunication Union (ITU), Geneva. Available at: https://www.itu.int/en/mediacentre/Documents/MediaRelations/ITU Facts and Figures 2019 - Embargoed 5 November 1200 CET.pdf.

Kamara A, Conteh A, Rhodes R E, et al. (2019) The Relevance of Smallholder Farming to African Agricultural Growth and Development. *Afr. J. Food Agric. Nutr. Dev* 19(1): 14043–14065. DOI: 10.18697/ajfand.84.BLFB1010.

Karanja L, Gakuo S, Kansiime M, et al. (2020) Impacts and challenges of ICT based scale-up campaigns: Lessons learnt from the use of SMS to support maize farmers in the UPTAKE project, Tanzania. *Data Science Journal* 19(1): 1–8. DOI: 10.5334/dsj-2020-007.

Kaur K and Kaur P (2018) Agricultural Extension Approaches to Enhance the Knowledge of Farmers. *International Journal of Current Microbiology and Applied Sciences* 7(2): 2367–2376. DOI: https://doi.org/10.20546/ijcmas.2018.702.289.

Kemp S (2019) *Digital 2019: Global Internet Use Accelerates*. New York. Available at: https://wearesocial.com/blog/2019/01/digital-2019-global-internet-use-accelerates.

Kikulwe EM, Fischer E and Qaim M (2014) Mobile Money , Smallholder Farmers , and Household Welfare in Kenya. *PLoS ONE* 9(10): e109804. DOI: 10.1371/journal.pone.0109804.

Konaté J, Diarra AG, Diarra SO, et al. (2020) SyrAgri: A Recommender System for Agriculture in Mali. *Information* 11(12): 561. DOI: 10.3390/info11120561.

Kotze T., Anderson O and Summerfield K (2016) www.econstor.eu. *South African Journal of Business Management* 47(1): 21–28. DOI: doi.org/10.4102/sajbm.v47i1.49.

Kotze TG, Anderson O and Summerfield K (2016) Technophobia: Gender differences in the adoption of high-technology consumer products. *South African Journal of Business Management* 47(1): 21–28. DOI: doi.org/10.4102/sajbm.v47i1.49.

Krell NT, Giroux SA, Guido Z, et al. (2021) Smallholder farmers ' use of mobile phone services in central Kenya.

Climate and Development 13(3). Taylor & Francis: 215–227. DOI: 10.1080/17565529.2020.1748847.

Krone M, Dannenberg P and Nduru G (2016) The use of modern information and communication technologies in smallholder agriculture : Examples from Kenya and Tanzania. *Information Development* 32(5): 1503–1512. DOI: 10.1177/0266666915611195.

Lexi B (2014) Introducing iCow-The Virtual Mobile Midwife for Cows-National Geographic Society Newsroom. Washington DC.

Lowder SK, Skoet J and Singh S (2014) What do we really know about the number and distribution of farms and family farms in the world? *ESA Working Paper*. 14–02. Rome.

Mabe LK and Oladele I (2015) E-Readiness Among Male and Female Extension Officers in North-West Province , South Africa. *Journal of Agricultural & Food Information* 16(4): 315–325. DOI: 10.1080/10496505.2015.1058166.

Mackay S (2019) *WeFarm - Connecting Small-Scale Farmers to the People and Resources They Need to be More Successful*. United Kingdom. Available at: https://www.agrilinks.org/users/sarahlouisemackay81#profile-main.

Magoro D and Hlungwani S (2014) The Role of Agricultural Extension in the 21 Century: Reflections from Africa. *International Journal of Agricultural Extension* 02(01): 89–93. Available at: https://www.cabdirect.org/cabdirect/abstract/20143242557.

Mapiye O, Makombe G, Mapiye C, et al. (2019) Management information sources and communication strategies for commercially oriented smallholder beef cattle producers in Limpopo province, South Africa. *Outlook on Agriculture* 49(1): 50–56. DOI: 10.1177/0030727019860273.

Marwa ME, Mburu J, Oburu REJ, et al. (2020) Impact of ICT Based Extension Services on Dairy Production and Household Welfare: The Case of iCow Service in Kenya. *Journal of Agricultural Science* 12(3): 1–12. DOI: 10.5539/jas.v12n3p141.

Mbanda-Obura SA, Tabu IM, Amudavi DM, et al. (2017) Determinants of choice of agricultural information sources and pathways among sorghum farmers in Ndhiwa sub-county, western Kenya. *International Journal of Agricultural Extension* 5(1): 39–49. Available at: https://escijournals.net/index.php/IJAE/article/view/2012.

McCole D, Culbertson MJ, Suvedi M, et al. (2014) Addressing the challenges of extension and advisory services in Uganda: The Grameen foundation's community knowledge worker program. *Journal of International Agricultural and Extension Education* 21(1): 6–18. DOI: 10.5191/jiaee.2014.20101.

Messenger C (2018) Digital Insights Malawi: Information and Communication in Rural Communities. Malawi: DAI.

Misaki E, Apiola M, Gaiani S, et al. (2018) Challenges facing sub-Saharan small-scale farmers in accessing farming information through mobile phones: A systematic literature review. *Electronic Journal of Information Systems in Developing Countries* 84(4): 1–12. DOI: 10.1002/isd2.12034.

Moyo-Nyede S and Ndoma S (2020) Limited Internet access in Zimbabwe a major hurdle for remote learning during pandemic. *AfroBarometer* (371): 1–11.

Myeni L, Moeletsi M, Thavhana M, et al. (2019) Barriers Affecting Sustainable Agricultural Productivity of Smallholder Farmers in the Eastern Free State of South Africa. *Sustainability* 11: 3003. DOI: 10.3390/su11113003.

Nakasone E, Torero M and Minten B (2013) The Power of Information: The ICT Revolution in Agricultural Development. *Annual Review of Resource Economics* 6(1): 533–550. DOI: 10.1146/annurev-resource-100913-012714.

Ogbeide OA and Ele I (2015) Smallholder Farmers and Mobile Phone Technology in Sub-Sahara Agriculture. *Mayfair Journal of Information and Technology Management in Agriculture (MJITMA)* 1(1): 1–19.

Ogutu SO, Okello, Julius J and Otieno DJ (2014) Impact of Information and Communication Technology-Based Market Information Services on Smallholder Farm Input Use and Productivity : The Case of Kenya. *World Development* 64. Elsevier Ltd: 311–321. DOI: 10.1016/j.worlddev.2014.06.011.

Qiang CZ, Kuek SC, Dymond A, et al. (2012) *Mobile Applications for Agriculture and Rural Development*. Washington DC.

Quandt A, Salerno JD, Neff JC, et al. (2020) Mobile phone use is associated with higher smallholder agricultural productivity in Tanzania, East Africa. *PLoS ONE* 15(18): 1–16. DOI: 10.1371/journal.pone.0237337.

Raidimi EM and Kabiti HM (2019) A Review of The Role of Agricultural Extension and Training in Achieving Sustainable Food Security: A Case of South Africa. *South African Journal of Agricultural Extension* 47(3): 120–130. DOI: http://dx.doi.org/10.17159/2413-3221/2019/v47n3a520.

Rashid AT and Laurant E (2014) Mobile Phones and Development: An Analysis of IDRC-Supported Projects. *The Electronic Journal of Information Systems in Developing Countries.* 36(2): 1–16. DOI: 10.1002/j.1681-4835.2009.tb00249.x.

Roy R (2009) Trends of ICT usage in Agriculture and Extension. *Bangladesh Research Publications Journal* 2(1): 307–318.

Rust JM and Rust T (2013) Climate change and livestock production: A review with emphasis on Africa. *South African Journal of Animal Sciences* 43(3): 256–267. DOI: 10.4314/sajas.v43i3.3.

Shrader L, Mukau E and Karylyn A (2019) *DigiFarm: A Digital Platform for Farmers- Case study*.

SNRD (2016) *Use of ICT for agriculture in GIZ projects- Status quo, opportunities and challenges*. *German Society for International Co-operation*. Sector Network Rural Development Africa (SNRD), Bonn and Eschborn.

Statista (2020) Telecommunications equipment - statistics and facts. Available at: https://www.statista.com/topics/2844/telecommunications-equipment/ (accessed 28 March 2021).

Steinfield C and Wyche S (2013) Assessing the Role of Information and Communication Technologies to Enhance Food Systems in Developing Countries. (November): 39.

Suri T and Jack W (2016) The long-run poverty and gender impacts of mobile money. *Science* 354(6317): 1288–1292. DOI: doi:10.1126/science.aah5309.

SVAI (2018) *DigiFarm Case study*. Johannesburg. Available at: https://www.svai.africa/2018/11/28/digifarm/.

Trendov N, Varas S and Zeng M (2019) *Digital technologies in Agriculture and Rural Areas*. Rome. DOI: 10.4324/9780429507533-13.

Tsan M, Totapally S, Hailu M, et al. (2019) *The Digitalisation of African Agriculture: Report 218-219*. Wageningen.

Van Campenhout B (2017) There is an app for that? The impact of community knowledge workers in Uganda. *Information Communication and Society* 20(4). Taylor and Francis: 530–550. DOI: 10.1080/1369118X.2016.1200644.

Van Schalkwyk F, Young A and Verhulst S (2017) *Ghana's Esoko: Leveling the Information Playing Field for Smallholder Farmers*. Available at: http://odimpact.org/files/case-esoko.pdf.

Verdier-chouchane A and Karagueuzian C (2016) Moving towards a green productive agriculture in Africa: The role of ICTs. *Africa Economic Brief* 7(7): 1–12.

WeFarm (2018) World's Largest Farmer-to-Farmer Network, Wefarm, Reaches over One Million Users. London. Available at: https://www.businesswire.com/news/home/20181008005527/en/World's-Largest-Farmer-to-Farmer-Network-Wefarm-Reaches-Million.

Wiggins S, Sabates-Wheeler R and Yaro J (2018) *Rural Transitions, Economies and Rural–Urban Links*. 011. United Kingdom. Available at: https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/13818.

World Bank (2016) *World Development Report 2016: Digital Dividends*. Washington DC: The World Bank. DOI: doi:10.1596/978-1-4648-0671-1.

World Bank (2017) *ICT in Agriculture: Connecting Smallholders to Knowledge, Networks, and Institutions*. Updated Ed. Washington DC: The World Bank.

Wyrzykowski R (2020) *Mobile connectivity in Sub-Saharan Africa: 4G and 3G connections overtake 2G for the first time*. United Kingdom. Available at: https://openknowledge.worldbank.org/handle/10986/19032 License: CC BY 3.0 IGO.".

Zyl O Van, Alexander T, Graaf L De, et al. (2014) *ICTs for Agriculture in Africa*. *eTransform Africa*. Washington DC. DOI: 10.1007/springerreference_77816.

Chapter 3: Research Methodology

3.1 Introduction

This chapter presents the study research methodology. The research paradigms, methods and design are presented. The analytical framework is also presented. The study was guided by the pragmatic paradigm which accommodates positivism (quantitative) and normative (qualitative) perspectives. A partially mixed sequential explanatory design with a dominant quantitative method was adopted. Figure 3.1 is a schematic representation of the research methodology highlighting the development of the partially mixed sequential (quantitative dominant) mixed research method. Lastly, the chapter presents the ethical considerations.

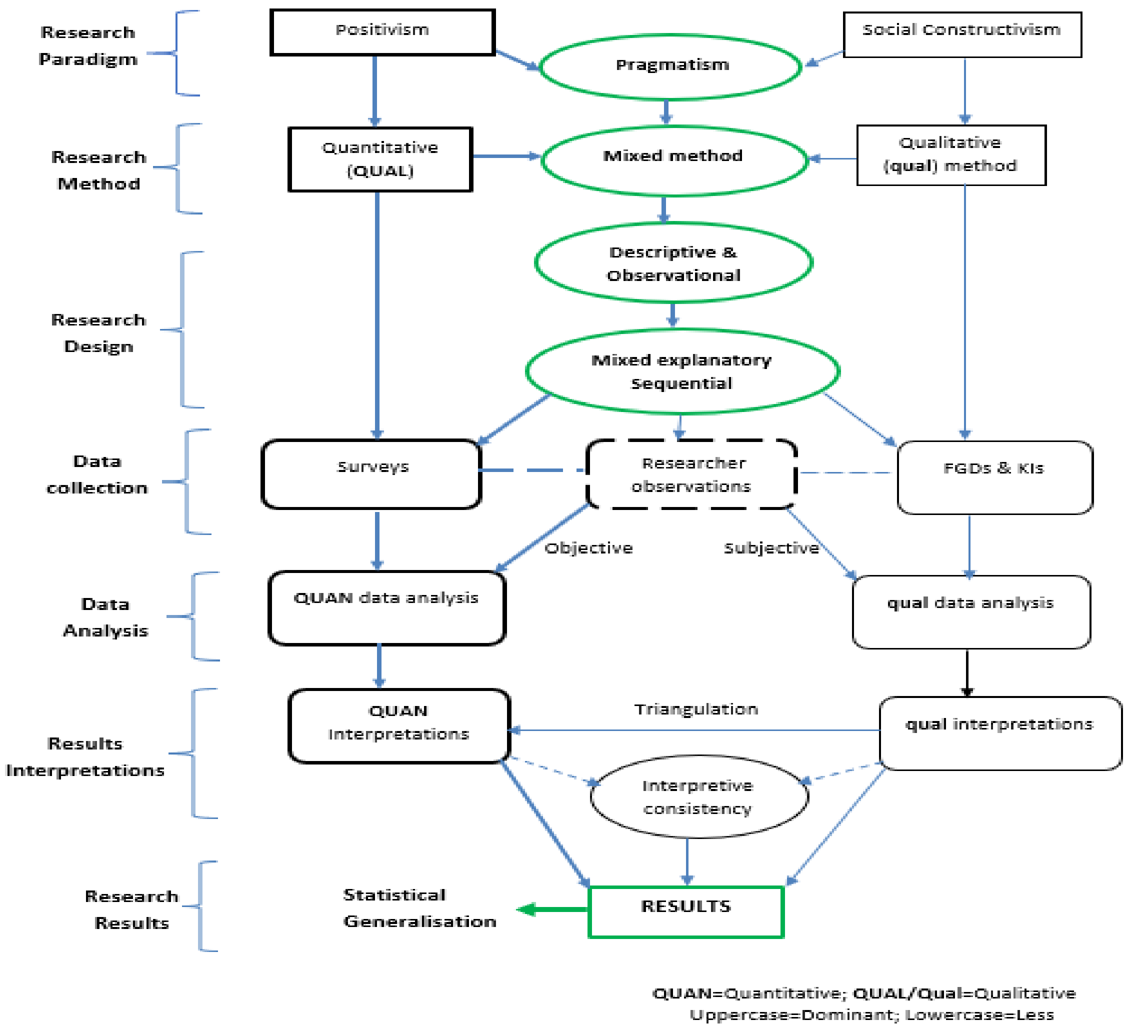

Figure 3. 1 A schematic representation of the research methodological framework

(Developed based on: Lincoln and Guba, 1985; Tashakkori and Teddlie, 2003; Bryman, 2004; Huberman and Miles, 2005; Hanson et al., 2005; Neuman, 2007; Collins et al., 2007; Makombe, 2017).

3.2 Research paradigm

It is imperative to position a research process philosophically. This positioning describes what the researcher believes concerning the nature of reality (ontology) and the nature of knowledge (epistemology) (Merriam, 2009). Kivunja and Kuyini (2017) and Makombe (2017) reiterated the importance of locating or grounding a research process in a paradigm. Bryman (2004) describes a research paradigm as a "collection of beliefs and dictates that influence what should be studied, how it should be studied, what instruments should be used, and how the results should be interpreted." Thus, it represents a researcher's world view defining patterns that can shape the study (Creswell, 2009; Kivunja and Kuyini, 2017) and determine methods to use (Makombe, 2017). This extends to how the researcher sees the world, interprets, and acts within that world. There are various paradigms through which a research process can be grounded. The current study was guided by a pragmatic paradigm which is a derivative of the combination of positivist and social constructivist paradigms.

3.2.1 Positivism paradigm

'Positivism' is commonly referred to as the scientific method (Creswell, 2003; Makombe, 2017). Research in this paradigm depends on deductive judgement to derive conclusions (Cohen et al., 2007; Kivunja and Kuyini, 2017) and the assumption that reality exists out there and is observable, stable and measurable (Merriam, 2009). Therefore, the researchers should try and uncover that reality by conducting research (Bryman, 2004). Positivism aims to offer descriptions and predictions of reality based on measurable outcomes (quantitative research). The computable outcomes are undergirded by four main assumptions which help researchers to understand meanings and expectations from research. These are generalisability, determinism, empiricism, and parsimony (Cohen et al., 2007; Kivunja and Kuyini, 2017). The generalizability assumption allows that the research findings be applied to other situations by inductive inferences. Determinism shows that other factors cause the observed events; hence the causal relationships among the factors should be understood, predictions made, and the potential impacts of the explanatory on dependent factors be controlled (Bryman, 2004). Empiricism entails that for a researcher to examine a research problem, there is a need to gather verifiable empirical data, which can sustain the theoretical framework opted for in the research and allow the researcher to test the formulated hypotheses. Finally, parsimony refers to the researcher's attempts to describe the phenomena in the most economical way possible (Kivunja and Kuyini, 2017). In the current study, the positivist orientation supported the quantitative approach in measuring the objective reality of the study phenomena. However, such a perspective excludes any likelihood of including metaphysical philosophies of ‘emotions’ or ‘subjective experience’ into the realms of social science information (Byman, 2004). Since the current study also aimed to explore in-depth experiences and perceptions from experienced and knowledgeable individuals regarding the use of ICTs in agricultural extension, the social constructivist paradigm was used to triangulate the positivist approach, as shown schematically in Figure 3.1.

3.2.2 Social constructivism

The social constructivist world view posits that realism is created through subjective meanings of human experiences (Creswell, 2003; 2009, 2014). According to the tenets of the paradigm, realism or understanding of the world is socially and collectively constructed (Cohen et al., 2007; Marriam, 2009). In the current study, the social constructivist paradigm allowed investigation of the phenomena from the viewpoint of the participants (farmers, and extension officers) while the investigator addressed the ‘process’ of interaction among individuals (Creswell, 2003). These viewpoints or interpretations of reality were presumed to be many and to vary among participants (Creswell, 2009). This coerced the researcher to consider looking for the complexity of these views and not just bracketing their meanings into a few categories or ideas (Creswell, 2003). Much broader research questions (open-ended) which allowed the participants to construct meanings of the situations, were used. Inquiry to such questions and social reality was achieved through conducting FGDs and by interviewing key informants.

3.2.3 Pragmatic paradigm

The pragmatic world view arose as a single paradigm in response to the debate concerning the “paradigm wars” (Armitage, 2007:3). Among the debating philosophers, using mono-paradigmatic positioning (either positivism or social constructivism) in research is considered inefficient. The arguments suggested that it was impossible for truth concerning the world to be reached by solely employing a single methodology as exclusively prescribed by either positivists or social constructivists (Almalki, 2016; Kivunja and Kuyini, 2017). They advocated for a paradigm that could be pluralistic and more practically efficient (Tashakkori and Teddlie, 2003). A paradigm that can collectively and efficiently investigate the real behaviour of respondents, the beliefs behind the exhibited behaviours, and the likely implications of their different behaviours (Kivunja and Kuyini, 2017). This influenced the development of the pragmatic paradigm. Pragmatists often relate the choices of methods directly to the role of and the kind of the research questions postured (Creswell, 2003).

Given that research in most cases has multiple roles, a "what works" strategy permits the examination of research questions that cannot be addressed by an exclusively quantitative or qualitative method (Tashakkori and Teddlie, 2003; Creswell, 2009:231). Therefore, researchers could combine methods, designs, and various procedures and develop a strategy that effectively describes and meets the research objectives (Creswell, 2003). Therefore, the pragmatic paradigm was used to accommodate a mixed-methods approach (Makombe, 2017). Pragmatism served as the grounding of this study.

3.3 Research methods

The inherent association between a research paradigm and research method is critical. Paradigms permeate the process of identifying research methods, designs and strategies for data collection and analysis to use (Kivunja and Kuyini, 2017). For instance, adopting a positivist paradigm entails quantitative data collection and analysis, while constructivism implies using qualitative methods. However, limitations and inaptness associated with mono-methods in studying certain research phenomena have reinforced arguments promoting the use of mixed methods approach, which entails combining quantitative and qualitative methods (Tashakkori and Teddlie, 2003; Almalki, 2016). For the current study, the research questions that required in-depth inquiry were investigated qualitatively, whereas questions requiring numerical exploration were studied quantitatively, with the qualitative being used to triangulate the quantitative method.

3.3.1 Quantitative method

Invariably, the concept of quantitative research is alleged to be positivist in conception and direction (Creswell, 2003; Neuman, 2007; Kivunja and Kuyini, 2017). The quantitative method is generally referred to as a scientific (Makombe, 2017), objective and deductive approach to research (Bryman, 2004; McMillan and Schumacher, 2010). The method follows a linear research path with strategies of investigation that produce numeric data and results (Neuman, 2007). Besides being conventionally associated with hard sciences (experiments), quantitative methods dominate the social science research field (Makombe, 2017). Within the social science field, quantitative methods often use the survey technique for data collection (Neuman, 2007; Creswell, 2003). The features (strengths and weaknesses) of quantitative research methods are summarised in Table 3.1.

Table 3. 1 Strengths and weaknesses of quantitative research methods

	Strengths	Weaknesses
a.	It can test and validate constructed theories on how and why phenomena occur.	The researchers' categories might not give a clear understanding to local constituencies.
b.	It is used to generalise research findings when appropriate random sampling is used.	Researchers miss important phenomena occurring due to hypothesis testing.
c.	It can be generalised and replicated for different population sizes	The knowledge produced might not be suitable for direct application to some local conditions and individuals.
d.	Data collection and analysis are faster and quicker than other methods	Less comprehensive information about a phenomenon is acquired
e.	It provides numerical and precise data	There is no detail of experience and thoughts on the situation in question
f.	Results are independent of the researcher's influence.	Largely works on figures and numbers only
g.	It has high credibility with politicians.	Because researchers are not part of the reality, they may tend to miss some important information.
h.	It is used for studying many people	It has limited credibility with administrators
i.	It can work on both hard sciences (experiments) and social science research	It is limited when studying real-time situations

(Source: Creswell, 2003; Bryman, 2004; Huberman and Miles, 1994; Makombe, 2017).

3.3.2 Qualitative method

The qualitative method was brought mainly due to rising disillusionment with quantitative research products and the philosophical need for promoting self-reflection and the diffusion of notions associated with phenomenology (Bryman, 2004). According to Neuman (2007) and Prion and Adamson (2014), qualitative methodology is more nonlinear, holistic, recurrent, and often described as an inductive-interpretive approach. It is largely "emic" or characterised by the perspective that participants are central in determining the truth and meaning of the phenomena under study (Prion and Adamson, 2014:1). It also sometimes entails a continual immersion of the inquirer among the individual subjects or groups to generate a rounded in-depth account of them and their society (Bryman, 2004). Its primary assumptions are that reality/realism is a social construct; there is difficulty in measuring complex and intertwined variables; there is a primacy of subject matter, and that the research data consists of respondents' viewpoints (Neuman, 2007). In qualitative methodology, researchers become primary instruments for collecting and analysing data or developing themes for data that is largely exploratory in nature using the 'how' and 'why' type of questions (Bryman, 2004; Merriam, 2009; Creswell, 2009;2014). In the current research, FDGs and KIIs were used to gather qualitative data. The strengths and weaknesses of qualitative methods are summarised in Table 3.2.

Table 3. 2 Strengths and Limitations of Qualitative Research

	Strengths	Weaknesses
a.	Researchers have a clear idea of what they will be looking for in advance.	Important variables might be missed from the qualitative analysis.
b.	The researcher becomes subject in the matter; hence more room for subjectivity	Too much information at a time and all data must be analysed, which takes time
c.	It produces more detailed description of phenomena	The researcher tends to influence the results.
d.	Qualitative data can be expressed in the form of words or pictures and objects.	Consumes more time than quantitative method.
e.	The design usually takes shape as the research unfolds	Outcomes are subjective hence it creates bias
f.	It explores various experiences and meanings that individuals or society give to a social issue or object	It is difficult to use in hard sciences (experiments)

Sources: (Huberman and Miles, 1994; Neuman, 2007, Creswell, 2009;14; Merriam, 2009)

3.3.2 Mixed methods approach

Mixed methods allow the researcher to base knowledge claims on pragmatic grounds (e.g., consequence-oriented, problem-centred, and pluralistic) (Creswell, 2003). It integrates qualitative and quantitative methods (Creswell, 2009; Almalki, 2016; Kivunja and Kuyini, 2017; Makombe, 2017) and, therefore, opens the avenues for different worldviews and, assumptions and the use of various means of data collection and analysis in understanding social reality (Tashakkori and Teddlie, 2003; Creswell, 2009; 2014). Thus, complementary strengths obtained from using the mixed methods approach contribute to the reliability and validity of the research process (Creswell, 2014) and hence the generalisability of findings from a sample to population (Hanson et al., 2005). According to Tashakkori and Teddlie (2003) and Almalki (2016), mixed methods are superior to mono-methods (quantitative or qualitative method) because they can address confirmatory and exploratory questions simultaneously. They can offer sturdier inferences through depth and breadth in answering questions from complex social phenomena. However, this method is time-consuming (Almalki, 2016), and the collection and analysis of both data types can be constrained by a lack of resources (Hanson et al., 2005). According to Bryman (2004), one of the barriers is the view that quantitative and qualitative studies are founded upon primarily discordant epistemological positions; hence they cannot be used together effectively. The strengths and weaknesses of mixed methods are summarised in Table 3.3.

Table 3. 3 Strengths and Limitations of Mixed Methods Research

	Strengths	Limitations
a.	A combination of qualitative and quantitative methods guarantees that no vital information is excluded	Largely constrained by time and resource availability to collect and analyse data
b.	It can answer research questions which cannot be answered by using mono-methods.	Research designing could be tedious and complex
c.	It can deal with both confirmatory and exploratory questions simultaneously	Choosing and mixing methods for a given inquiry purpose remains difficult
d.	It can produce sturdier inferences through depth and breadth in answering to complex social phenomena	
e.	A deeper understanding of the research problem	

Source: (Tashakkori and Teddlie 2003; Hanson et al., 2005; Creswell, 2003; 2009; Flick, 2017)

3.4 Research design

Creswell (2003;2014) considers research design as different types of enquiries or a reflection upon the researcher's ideas. The current study adopted an observational and descriptive design. Observational design is a technique whereby the researcher engages in multiple observations and develops observational notes during data collection (Creswell, 2014). Descriptive design is generally a scientific method involving accurate and systematic descriptions of a population or situation without influencing it (Neuman, 2007). A descriptive design can use various quantitative and qualitative methods to investigate the study phenomenon.

The research methodology aimed to use qualitative methods to explain quantitative methods (explanatory research) further. However, after mixing the two methods, they can be used concurrently or sequentially (Onwuegbuzie and Collins, 2007). A sequential mixed design was, therefore, adapted for use in this study as presented in Hanson et al. (2005) and Creswell (2009; 2014).

3.4.1 Sequential explanatory design

The mixed methods sequential explanatory design comprises two distinct phases: quantitative and qualitative data collection and analysis (Hanson et al., 2005; Doyle et al., 2009; Creswell, 2009). However, relative weighting (priority in answering the research questions) of the two methods must be considered (Hanson et al., 2005). Therefore, in this current study, the quantitative method was dominant. The researcher first collected and preliminarily analysed the quantitative (numeric) data. After that, the qualitative (text) data were collected and analysed in that sequence to help in explaining or elaborating on the quantitative findings obtained in the first phase (triangulating) (Creswell, 2014; Almalki, 2016). This means that the qualitative phase builds on the quantitative phase, and partial mixing was done in the interpretation, discussion, and generalisation of results (Bryman, 2004; Hanson et al., 2005). The questions in the qualitative phase were also informed by field observations during quantitative data collection and preliminary analysis of the quantitative data. Figure 3.2 presents the model for mixed methods sequential explanatory research design used.

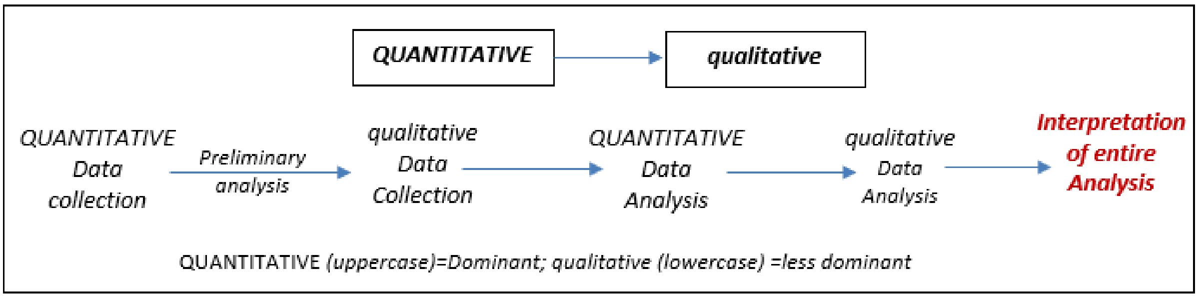

Figure 3. 2 Mixed methods sequential explanatory design model
(Based on: Hanson et al., 2005; Creswell, 2009; 2014)

Sampling design

The study employed a two-dimensional mixed method sampling design to determine the sampling scheme and sample size(s) for quantitative and qualitative phases (Collins et al., 2007). Furthermore, this design aided in identifying the relationships among the samples. The sampling scheme denotes the explicit approach used in selecting the samples (Collins et al., 2007). In this study, the survey sample (quantitative phase) was composed of all farmers in the targeted population (census approach). FGDs samples were purposively selected from the survey sample (used in the quantitative phase) with assistance from extension officers. The sample size for the survey was determined by the target population of farmers who were 101. The FGD sample size (between 6 and 12 respondents) was based on the recommendations by Neuman (2007), Collins et al. (2007), and Creswell (2009).

According to Onwuegbuzie and Collins (2007), the relationships of the quantitative and qualitative samples can be identical, parallel, nested, or multilevel. An identical sampling design indicates that similar sample members participate in both quantitative and qualitative stages of the investigation (Collins et al., 2007). Contrastingly, a parallel sampling design denotes that the samples for quantitative and qualitative phases of the study are different but drawn from the same target population (Collins et al., 2007). A nested sampling design or relationship indicates that the sample participants for one investigation phase represent a subset of participants selected for the other phase of the study (Onwuegbuzie and Collins, 2007). In the current study, FGD members (qualitative phase) were selected from the survey sample (quantitative phase) in a similar way to the study by Igo et al. (2005). Finally, a multilevel sampling design involves using two or more samples that are identified from different levels of the study enquiry (Collins et al., 2007). In this study, KII samples (livestock extension officers) had samples that were different from the survey sample (farmers) as used in a study by Drennan (2002).

3.5 Ensuring reliability and validity in the quantitative research

Reliability and validity are central issues in quantitative research (Creswell, 2003; Golafshani, 2003; Bryman, 2004; Neuman, 2007). To increase confidence in the research process and findings, the instrument (questionnaire) must be both accurate and consistent (Del Greco et al., 1987; Taherdoost, 2016). Meticulous consideration of meeting the validity and reliability conditions has helped improve the present research quality. Perfect validity and reliability are practically impossible to achieve (Cohen et al., 2007; Neuman, 2007). However, various activities and measures were implemented to optimise the level of validity and reliability in the current study.

3.5.1 Ensuring validity and reliability

Validity explains the degree to which the measurement instrument is precise (measuring what it meant to measure) (Golafashani, 2003; Bryman, 2004). Validity can be divided into internal and external validity. According to Cohen et al. (2007), internal validity seeks to prove that an event or set of data explained through a research activity can truly be sustained by the data collected. External validity explains the capacity to generalize from survey investigation to broader populations as well as different cases and settings (Neuman, 2007). It represents the truthfulness of the findings. The validity test was primarily divided into four types for the current study: content validity, face validity, criterion-related validity, and construct validity as prescribed in Creswell (2009).

1. ***Content validity*** defines the level to which actual questions presented on the survey instrument and their respective scores represent all possible research questions about the research construct or domain (Creswell, 2009). The instrument was assessed to check if it fairly and broadly covers the domain or

realm it was intended to cover. Comprehensive domain analysis was conducted by firstly specifying a full content of the domain relevant to the study issue, then selecting specific areas from the content and converting them into testable research questions. As suggested by (Taherdoost, 2016), this process of improving the questionnaire's content validity was conducted with assistance from experienced research investigators. All unclear and ambiguous questions were corrected, and the unproductive and non-functioning ones were removed based on advice from experts (Del Greco et al., 1987). Such processes were repeated until the instrument met the expected quality standards.

2. ***Face validity*** refers to the degree to which a test appears to measure what it claims to measure (Taherdoost, 2016). Face validity can be simply assumed when the instrument has content validity. This is because it is generally considered a rudimentary and a minimum index of content validity (Allen and Yen, 1979). Generally, the questionnaire was designed to ensure its practicability, readability, uniformity of style and formatting. The simplicity of the language used was also checked to evaluate and elevate face validity (Taherdoost, 2016). Professional-looking survey instruments have higher chances of eliciting serious responses from the respondents (Del Greco et al., 1987).
3. ***Criterion validity*** involved relating findings from the main survey instrument to another external criterion (Cohen et al., 2007). This was to ensure that the instrument effectively measured what it purports to measure (Del Greco, 1987). In the present study, the responses on the developed questionnaire were checked to see if they correlate with researcher observations and previous findings from literature (pre-testing, section 3.5.3).
4. ***Construct validity***

   The concept of methodological triangulation was central in improving validity in the current study. The concept was conceived as a strategy to improve validation by combining two methodologies in studying the same phenomenon (Denzin, 1978). Therefore, qualitative data and results were used to corroborate and confirm the quantitative findings to improve the validity of the study results (Creswell, 2003; Bryman, 2004). Besides the convergence of findings, the use of triangulation became a source of extra knowledge, especially regarding the in-depth experiences and perceptions about the usefulness of the LMDS in improving extension and farm management in South Africa harnessed through FGDs and KII. As noted in Flick (2017), within the current study, triangulation was treated as a systematic initiative extending from the theoretical and epistemological backgrounds of the methods combined in the design.

3.5.2 Ensuring reliability in quantitative research

Reliability is the degree to which a research instrument produces stable and consistent results or scores (Del Greco et al., 1987; Bryman, 2004; Creswell, 2009). It ensures that the scores obtained by the instruments remain the same when the tool is repeatedly administered at different times. Therefore, reliability, or reproducibility, is commonly used to mean consistency, dependability, replicability, or repeatability of measurement (Golafshani, 2003; Neuman, 2007; Kivunja and Kuyini, 2017). To measure the reliability of the research instrument, Cronbach's alpha score was used. Cronbach's alpha is the most used measure of internal consistency and repeatability (proxies of reliability) of research instruments in quantitative studies (Neuman, 2007; Taherdoost, 2016). The coefficient measures unidimensionality or internal coherence of items on a scale (Bryman, 2004; Neuman, 2006). The Cronbach's alpha was computed using SAS. Based on Neuman (2007); Garson (2013), a coefficient of less than 0.6 was considered unreliable, while above 0.70 is considered reliable. Following Arifin (2018), the empirical formula for Cronbach's alpha adopted for the study was:

$$\alpha = \left(\frac{k}{k-1}\right)\left(\frac{Sy^2 - \sum Si^2}{Sy^2}\right)$$

Where k is number of items in a scale, Si^2 is the variance of i^{th} item and Sy^2 is the variance of the scale (total) scores. The reliability coefficient for the current study was found to be 0.791.

Triangulation (discussed under section 3.5.1) was also used to ensure reliability. Triangulation increases reliability by reducing methodological errors (Garson, 2013). Thus, using multiple methods of measurement (surveys, FGD, KIIs and researcher observations) in the current study helped in reducing the likelihood of the occurrence of systematic errors.

3.6 Quantitative data collection

3.6.1 Survey

The current study used a survey design to collect quantitative data. Researchers mostly use surveys in descriptive or explanatory design studies (Neuman, 2007). These designs are some of the main vehicles for quantitative research data collection in the social sciences (Bryman, 2004). Surveys provided a numeric description of the studied population's trends, attitudes, beliefs, opinions, and characteristics (Neuman, 2007; Creswell, 2014). Questionnaires are used for gathering survey information (numeric data) in the social science research field (Cohen et al., 2007; Taherdoost, 2016). A structured questionnaire (Appendix 1) was developed and used as the survey instrument in the current study. It was furnished with simple and straightforward closed-ended questions and a few open-ended questions based on study objectives. The instrument was pre-tested before use. The advantages and disadvantages of the survey Face-to-Face Interviews with Questionnaire Table 3.4.

Table 3. 4 Advantages and disadvantages of the survey Face-to-Face Interviews with Questionnaire.

	Strengths	Weaknesses
a.	Possibility of collecting supplementary information.	Biasedness of potential participants due to high flexibility.
b.	Interviewers have control of the interview situation	Tedious and time-consuming
c.	High response rate. Easier and quicker to get responses	Survey questions may suggest ideas or options that respondents do not have
d.	Allows high flexibility in the questioning process.	Higher costs
e.	It can be used to gather more sensitive and threatening information	Possibility of under reporting by respondents
f.	Data is easier to code and analyse	Misinterpretation of questions may go unnoticed
g.		Surveys sometimes force respondents to give simplistic responses to complex issues

Source: (Neuman, 2007)

3.6.1.1 Pretesting the questionnaire

The survey questionnaire was pre-tested with a sample of 10 farmers. This activity was conducted because of its essentiality in improving the instrument's validity and the generation of reliable data for the study (Cohen et al., 2007). Some of the considerations and pre-testing activities were:

- Making sure that respondents were able to interpret and respond effectively to the questions.
- Elimination of ambiguities or difficulties in wording and making sure all questions were collecting the desired data

- Eliminating and rephrasing emotional and sensitive language
- Identifying any omissions, redundant and irrelevant items
- Gaining feedback on leading questions from the target respondents
- Gaining feedback on the layout, sectionalizing, numbering, and itemization of the instrument from the enumerators
- Assessing the time needed to complete the interview and determining the length and breadth of the instrument to keep the respondent's burden at an acceptable level.

All necessary adjustments were made to the instrument based on findings from the pre-testing exercise. Thus, some questions were re-written, some removed, and some added (Del Greco, 1987). The final survey questionnaire (Appendix 1) was then administered through face-to-face interviews (Cohen et al., 2007) and took on average 1 hour to administer.

3.7 Ensuring rigor and trustworthiness in qualitative research

Qualitative methods have a possibility of subjectivity (Cohen et al., 2007); hence researchers should always be concerned about achieving rigor. However, given that researchers themselves are, in most cases, part of the instruments for data collection in qualitative research, rigor becomes a challenge to achieve (Cohen et al., 2007). Rigor is concerned with the quality of the research process or being accurate. Ensuring reliability, validity, and transparency in the research design are significant conditions for rigor in qualitative research. These conditions were ensured through the implementation of various verification measures and self-correcting strategies during the research process. According to Prion and Adamson (2014), rigor can be expressed as a standard for the trustworthiness of the data collection process, analysis, and interpretation of the findings. Trustworthiness entails the level of trust and confidence which readers have in the findings. The criteria for achieving trustworthiness were based on four key components: credibility, dependability, conformability, and transferability (Lincoln and Guba, 1985).

1. ***Credibility*** is the truthfulness of the research data and interpretation of its findings (Prion and Adamson, 2014). It creates the assurance that the results are accurate and believable (Lincoln and Guba, 1985). In the current study, peer debriefing or review meetings (Creswell, 2009; Prion and Adamson, 2014) were regularly conducted with study leaders to review the process. This was also done to strengthen the

researcher's knowledge and skills of conducting qualitative research and ensure trustworthiness. Good rapport with the participants was maintained by being friendly and interactive with them (Creswell, 2009). This involved using local or common language on all engagements with respondents (use of interpreter where necessary), compliance with culture and putting value to their traditions and beliefs. The hired enumerators were all from the same province as the respondents and spoke their language. More experience of interacting with participants and their setting increases trustworthiness.

2. ***Confirmability,*** also known as neutrality, involves the process of clearly delineating the researcher's perspective about the research (Prion and Adamson, 2014). Realistically, it attempts to confirm the absence of researcher bias and assumptions, which of course, cannot be completely eliminated in qualitative research (Prion and Adamson, 2014). This extends the assurance that the research findings would be accepted by other researchers (Lincoln and Guba, 1985). In the current study, confirmability was increased through intensive reviews of the analytical results and interpretation by study leaders and other experts to reduce subjectivity. There were various mixes of audit trails, including computer records, email memos, reflexive field notes, and correspondences that the researcher kept ensuring confirmability. Apart from that, methodological triangulation (e.g., KIIs, FGDs, observations), data sources triangulation (e.g., Key informants, FGD discussants and investigator observations) were also used to improve confirmability, as suggested by Lincoln and Guba (1985).
3. ***Dependability*** ensures that similar research results can be obtained after repeating the study with the same respondents, coders, and context (Lincoln and Guba, 1985). Also known as auditability (Prion and Adamson, 2014), dependability posits the ease with which other researchers can replicate the current qualitative methodological process and reach comparable conclusions. To ensure the dependability of the study design and results, the researcher provided a comprehensive description of the research methodology. These were detailed and auditable track records describing the assumed research paradigm, research methods and designs used, and the processes of data collection, analysis, and interpretation of the results.
4. ***Transferability*** is comparable to generalisability in quantitative research (Lincoln and Guba, 1985). It refers to how much other researchers can confirm the results. According to Prion and Adamson (2014), it is the applicability of the research results to other settings. To ensure transferability, the research methodology was stated comprehensively and clearly.

3.8 Qualitative data collection

3.8.1 Focus Group Discussion (FGD)

FGDs were defined by Neuman (2007:300) as important qualitative research procedures where respondents are informally "interviewed" in a group set up to collect data. In the current study, data collected comprised experiences, perceptions, and suggestions about introducing and using ICT-based strategy (LMDS) in agricultural extension and farm management. An FGD guide was developed to facilitate the discussions and elicit in-depth views and opinions of the participants (Appendix 2). It helped keep the meeting on track while permitting respondents to discuss freely and naturally the topics to be covered. (Creswell, 2014). In each study area, an FGD facilitator was hired to facilitate the discussions. Neuman (2007) suggested that recruited facilitators should allow the discussants to engage mutually and naturally and make sure the discussion remains focused. Some of the qualities expected of them include being able to speak the respondents' language, being culturally sensitive (non-judgemental), and having empathy and politeness towards the participants.

3.8.1.1 Logistical arrangements and procedures followed in conducting the FGDs

The following logistical arrangements and procedures were followed in conducting the FGDs (Neuman, 2007; Creswell, 2014):

1. Participants were selected and formally invited two weeks before the session. An invitation letter was sent to all selected participants through their extension officers. They were also reminded about the meeting two days before the session through telephone calls.
2. During the selection of participants, a representative group composed of smallholder livestock (cattle) farmers were purposively selected from the previously used sampling frame. Four FGD sessions were conducted.
3. One week before conducting the discussions, facilitators were recruited and briefed about the whole FGD study, the discussion topics/themes to be covered and some general characteristics of the respondents. To ensure attendance and effective participation, transport and lunch were provided

as a small gesture of appreciation and venues were identified from within the communities, which allowed farmers to feel free and talk openly while having assurance for some privacy.

4. Name tents/tags were developed so that all participants, including the facilitators and their helpers, could be easily identified especially by the facilitator.
5. During the group discussion, a semi-circular seating arrangement was adopted to facilitate face-to-face interactions by participants and for the facilitator to closely engage with everyone.
6. Before the discussions started, all participants were served with two consent forms (one for them and another researcher) to read and sign as proof of consent to participate in the study.
7. The discussions were tape-recorded, and notes were also taken to capture main points and other group dynamics that could not be recorded, such as nonverbal expressions and the physical environment. Verbatim transcriptions of the audio records into English were done with assistance from postgraduate students who had good proficiency in the language used, and expert translator then checked them. The strength and weaknesses of FDGs are summarised in Table 3.5.

Table 3. 5 Strengths and Weaknesses of FGDs

	Strengths	Weaknesses
a.	The natural setting allows people to express opinions or ideas freely	A polarisation effect exists (attitudes can become more extreme after group discussion)
b.	Open expression among members of the marginalised groups is encouraged	Only one or a few topics can be discussed in FGD
c.	People tend to feel empowered, especially in action-oriented research projects	A moderator may unknowingly limit open, free expression of group members.
d.	Survey researchers are provided with a window into how people talk about survey topics	Focus group participants produce fewer ideas than in individual interviews
e.	The interpretation of quantitative survey results is facilitated	FGD rarely report all details of study design /procedure
f.	Participants may query one another and explain their answers to each other	Researchers cannot reconcile the differences that arise between individual-only and FGD context responses
g.		Extroverts can dominate the discussions
h.	The researcher becomes subject in the matter	The researcher tends to influence the results

Sources: (Neuman, 2007)

3.8.2 Key Informant Interviews

KIIs were conducted with livestock extension officers. Participants were chosen from different districts, with different ages and educational levels, and with varying levels of work experience in order to achieve as representative a sample as possible. The diversity opens for a wider range of perspectives and reduces the risk of having one-sided or biased conclusions. Six extension officers from the Department of Agriculture were interviewed. The extension officers were selected from the districts where the surveys were conducted. KIIs captured in-depth information about methods used to deliver extension services and challenges faced, the perceived potential of using ICT-based strategies, and how the initiative can impact smallholder farmers' effectiveness and sustainability. Interviewees were also asked to provide recommendations towards the proposed LMDS.

All interviews were conducted face-to-face by use of a semi-structured interview guide (Appendix 3). Individual face-to-face interviews promoted an effective exchange of ideas and the chance to explore more complex questions and get more detailed responses (including nonverbal responses). The interviews were audio-taped and later transcribed verbatim by the researcher. The interviewer was also taking notes to capture the main points highlighted by the interviewees. Table 3.6 presents the strengths and weaknesses of using KIIs.

Table 3. 6 Advantages and disadvantage of KIIs

	Strengths	Weaknesses
a.	Respondents have the chance to answer in detail hence they can qualify and quantify responses.	It is difficult to make comparisons and statistical analyses with data from open-ended questions
b.	Unanticipated findings can be discovered	Sometimes respondents may give different degrees of detail in their answers
c.	Answers to complex issues can be obtained	A respondent may give irrelevant responses or responses that are buried in useless detail.
d.	They permit creativity, self-expression, and richness of detail	Data transcription and coding could be very difficult and time consuming
e.		Questions may be too general to respondents who lose direction

Source: (Neuman, 2007)

3. 9 Analytical framework

Qualitative data analysis was conducted after a preliminary analysis of the quantitative data. Given that qualitative data were being used to triangulate quantitative results (Creswell, 2014; Almalki, 2016), the mixing of the results to achieve interpretive consistency (Figure 3.1) was done during the interpretation, discussion, and generalisation of results (Bryman, 2004; Hanson et al., 2005). The results were interpreted collectively, with the qualitative analysis triangulating the quantitative. Strategies of achieving "reliability and validity" (Ceswell, 2003; Neuman, 2007) in quantitative research inquiry as well as "rigor and trustworthiness" (Lincoln and Guba, 1985; Adamson, 2014) in qualitative research are discussed.

3.9.1 Quantitative analysis

All quantitative data were analysed using Statistical Analysis System (SAS) v. 9.4 (SAS Institute, 2012). Thus, using the PROC FREQ of SAS, descriptive statistical analysis was used to analyse and summarise the farmers' demographic profiles and farm information, perceptions on the usefulness of ICTs in livestock production, and their willingness to pay for improving rangelands. Descriptive statistics (frequency counts, percentages, and cross-tabulations) are used to describe the features of the data that help in understanding the research questions.

This study employed a bivariate probit model on the data collected through the double-bound dichotomous elicitation method to estimate the respondents' WTP for improving their rangelands. The bivariate probit model is a general parametric model of two-response surveys (Haab and McConnell, 2003). Following Wooldridge (2012), a binary logistic regression model was used to determine factors influencing farmers' WTP for ecosystem services (improving rangelands).

Farmers' perceptions were categorised into low perception, moderately high perception and high perception and the perception indexes were computed following Prodhan and Afrad (2014) and Shiduzzaman et al. (2018). In order to predict respondents' perception of the value of the LMDS based on their socioeconomic factors, Ordinal Logistic Regression (OLR) (proportional odds/parallel-lines model) was used. The reason for using the OLR is that the dependent variable is categorical and ordinal (Grilli and Rampichini, 2014; Lee, 2019). This model is based on cumulative distribution function (Ananth and Kleinbaum, 1997); hence it takes precedence over Multinomial Logistic Regression and the Principal Component Analysis (PCA), which could have been used.

3.9.2 Qualitative Analysis

3.9.2.1 Thematic analysis of qualitative data

The analysis of all qualitative data was undertaken by following a framework of the thematic analysis presented in Braun and Clarke (2006) and Mauire and Delahunt (2017) using the Atlas-ti V8 software. Thematic analysis was defined by Braun and Clarke (2006:6) as "a method for identifying, analysing, and reporting patterns (themes) within data." It, therefore, minimally organises and describes the data set in detail. In a study by Sawrikar (2019) on the application of thematic analysis in analysing FGD data with consumers and carers of mental illness, thematic analysis was treated as a two-step process involving identifying broad or key themes emerging from the data (coding), and then giving deeper meanings about them (narrative).

3.11 Ethical considerations

Ethical issues are essential in research, particularly focusing on human participants and should always be considered (Cohen et al., 2007). The research was approved by the University's Research Ethics Committee (Human ethical clearance: SU project number 9293). Research ethical clearance improves the protection of the research participants' rights, interests, and welfare (McMillan and Schumacher, 2010). The approved protocol provided responsibilities and guidelines that the investigator and the research team followed during participants' enrolment and research. Approved consent documents were issued to all research participants to read and consent to participate by signing them before any data collection interviews or discussions were conducted. The consent provided a fair explanation of the research purpose, its importance and what was expected from them. It assured research participants of privacy, confidentiality, and anonymity (Neuman, 2006; Cohen et al., 2007, Surmiak, 2020), especially regarding their names or identity. Thus, the participants were informed that personal information and responses will be kept strictly confidential and can only be disclosed with their permission or as required by law. During FGDs and KIIs, the participants were informed that the meetings were being audio recorded, and the recordings will be kept on a password-protected computer for a period recommended by the university and later permanently destroyed.

In addition, the consent forms provided that participants had the right to withdraw consent and discontinue participation in the study at any time; they could also decline to answer questions they did not wish to answer and remain in the discussion. Data collection enumerators were also asked to sign consent forms before engaging with the respondents.

3.12 Summary

This chapter discussed the research methodology and strategies and specific activities adopted to meet the study's objectives. The discussions showed that paradigms, epistemological and ontological research positions wield substantial influence on the choice of methodology. The study was founded on a pragmatic paradigm anchored by positivists and social constructivists assumptions and perspectives. The mixed method approach, which allowed the researcher to base knowledge claims on pragmatic grounds, was adopted for the study. The mixed method integrates quantitative and qualitative methods. Therefore, it has the capacity to address questions that cannot be exclusively addressed by either the quantitative or qualitative methods. A descriptive and explanatory design was adopted in which quantitative data were collected first (survey questionnaire) followed by qualitative data (FGDs and KIIs), which were performed after preliminary analysis of the quantitative data. Furthermore, in-depth information regarding the South African agricultural extension system and the potential of infusing it with ICT-based strategy were explored qualitatively. Researcher observations were also employed in quantitative and qualitative methods to enhance understanding of reality. The processes of achieving validity and reliability in quantitative methodology were discussed. The need for rigor and trustworthiness in qualitative research was also discussed and how they were achieved. The quantitative and qualitative data analysis methods and tools were also presented.

3.13 References

Anath V V and Kleinbaum D G (1997) Regression models for ordinal responses: Reviews of methods and applications, *International Journal of Epidemiology,* Vol 26 (6)

Allen M J and Yen W M (1979. *Introduction to measurement theory.* Monterey, Calif.: Brooks/Cole Pub. Co

Almalki S (2016) Integrating Quantitative and Qualitative Data in Mixed Methods Research-Challenges and Benefits. *Journal of Education and Learning;* Vol. 5, No. 3; 2016

Arifin W N and Malaysia S (2018) *Calculating the Cronbach's alpha coefficients for measurement scales with" not applicable" option*. Universiti Sains Malaysia, pp.1–8.

Armitage A (2007) *Mutual Research Designs: Redefining Mixed Methods Research Design, Paper presented at the British Educational Research Association Annual Conference*, Institute of Education, University of London, 5-8 September 2007

Braun V and Clarke V (2006) Using thematic analysis in psychology Using thematic analysis in psychology. *Qualitative Research in Psychology* 3(2): 77–101. DOI: http://dx.doi.org/10.1191/1478088706qp063oa.

Bryman A (2004) *Quantity and Quality in Social Research*. London and New York, 2nd Ed.

Cohen, L., Manion, L. and Morrison, K. (2007) *Research Methods in Education*, 6th Edition, Taylor and Francis e-Library, London and New York, ISBN 0-203-02905-4 Master e-book ISBN

Collins K M T Onwuegbuzie A J and Jia Q G (2007). A Mixed Methods Investigation of Mixed Methods Sampling Designs in Social and Health Science Research, *Journal of Mixed Methods Research*, 1(3): 267-294

Creswell J W (2003) *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*. London: Sage. 2nd ed.

Creswell J W (2009) *Research design. Qualitative, quantitative and mixed methods approach*. Los Angeles, CA: Sage.

Creswell J W (2014) *Research Design; Quantitative, Qualitative and Mixed Methods Approaches*. 4th ed. London:

Sage Publications.

Del Greco L (1987) *Questionnaire development: 2. Validity and reliability*, Canadian Medical Association Journal, Vol 136, 699-700

Denzin N (1978) *Sociological Methods: Sourcebook,* New York, NY: McGraw-Hill.

Drennan J (2002) An evaluation of the role of the clinical placement coordinator in student nurse support in the clinical area. *Journal of Advanced Nursing*, 40, 475-483.

Doyle L Brady A M and Byrne G (2009) An overview of mixed methods research. Journal of Research in Nursing, 14(2), 175-185.

Flick U (2016) Mantras and Myths: The Disenchantment of Mixed-Methods Research and Revisiting Triangulation as a Perspective, *Qualitative Inquiry,* Vol. 23(1) 46–57

Garson G.D (2013) *Validity and Reliability. Statistical Publishing Associates.* Asheboro North Carolina: Blue Books.

Golafshani N (2003) Understanding reliability and Validity in qualitative research, *The qualitative Report*, 8(4), 597-606

Grilli L and Rampichini C (2014) *Ordered logit model. In*: Michalos AC (Ed.). Encyclopedia of Quality of Life and Well-Being Research. Dordrecht, Netherlands: Springer, pp4510-4513

Hanson W Creswell J W Clark V P Petska P and Creswell JD (2005) Mixed methods research designs in counselling psychology. *Journal of Counselling Psychology,* 52 (2): 224–235.

Hanemann M Loomis J and Kanninen B (1991). Statistical efficiency of double-bounded dichotomous choice contingent valuation. *Am. J. Agric. Econ. Vol* 73, 1255–1263.

Huberman A and Miles M B (1994) *Data Management and Analysis Methods*. In N. Denzin. and Y.S. Lincoln (Eds.), Handbook of Qualitative Research, CA US: Thousand Oaks Sage Publications, 643 pp.

Igo L B Bruning R and McCrudden M T (2005). Exploring differences in students' copy-and-paste decision making and processing: A mixed-methods study. *Journal of Educational Psychology,* 97, 103-116.

Kivunja C and Kuyini A B (2017) Understanding and Applying Research Paradigms in Educational Contexts. *International Journal of Higher Education* Vol. 6, No. 5; 2017

Lee E (2019) *Ordinal Logistic Regression and its Assumptions -Full Analysis: A detailed Ordinal Logistic Regression analysis* on UN's 2019 World Happiness Report

Lincoln YS and Guba EG (1985) *Naturalistic inquir*y. Beverley Hills, CA: Sage.

Maguire M and Delahunt B (2017) Doing a thematic analysis: A practical, step-by-step guide for learning and teaching scholars. AISHE-J: The All Ireland, *Journal of Teaching and Learning in Higher Education* 9 (3)

Merriam S B (2009) Qualitative research: A guide to design and implementation. San Francisco, CA: Jossey-Bass.

Makombe G (2017) An Expose of the Relationship between Paradigm, Method and Design in Research. The Qualitative Report, 22(12), 3363-3382.

McMillan J H and Schumacher S (2010) *Research in education: evidence-based inquiry* (7th ed.). Boston: Pearson Education, Inc.

Nauman W L (2006) *Basics of Social Research - Qualitative and Quantitative Approaches*, 2nd Ed, Pearson Education

Onwuegbuzie A J and Collins K M (2007). A Typology of Mixed Methods Sampling Designs in Social Science Research. *The Qualitative Report,* 12(2), 281-316.

Prion S and Adamson K A (2014) *Making Sense of Methods and Measurement: Rigor in Qualitative Research, Clinical Simulation in Nursing* (ELSERVIER) 10, e107-e108

Prodhan F A and Afrad MS (2014) Knowledge and perception of extension workers towards ICT-utilization in agricultural extension service delivery in Gazipur District of Bangladesh, *Int. J. Agril. Res. Innov.* and *Tech*. 4 (2): 46-52.

SAS Institute (2012) SAS/STAT User's Guide. 9.3. New York city.

Sawrikar P (2019) Thematic Analysis of Focus Groups with Consumers and Carers of Mental Illness, SAGE research methods datasets, SAGE.

Shiduzzaman M Akhter H Ahmed M B and Islam M M (2018). Farmers' perception of beneficial effects and limitations of vermicompost. *Res. Agric. Livest. Fish*. 5 (1): 19-25.

Surmiak A (2020) Ethical Concerns of Paying Cash to Vulnerable Participants: The Qualitative Researchers' Views. *The Qualitative Report*, 25(12), 4461-4481. Retrieved from https://nsuworks.nova.edu/tqr/vol25/iss12/15.

Taherdoost H (2016) Validity and Reliability of the Research Instrument; How to Test the Validation of a Questionnaire/Survey in a Research. *International Journal of Academic Research in Management* (IJARM) Vol. 5, No. 3, 2016, Page: 28-36.

Tashakkori A and Teddlie C (Eds) (2003) *Handbook of Mixed Methods in Social and Behavioural Research*, Sage, California.

Wooldridge JM (2012) *Introductory Econometrics: A Modern Approach*. 6th ed. Cincinnati, USA: South-Western College Publishing.

Chapter 4: Commercially oriented smallholder cattle producers' willingness to pay for rangeland ecosystem services and its determinants in North West Province, South Africa

Abstract

The depletion and scarcity of rangeland ecosystems have become widespread and acute, especially in the arid and semi-arid cattle-producing regions. Therefore, pricing of rangelands improvement as a signal of scarcity and unsustainable use can promote users' willingness to conserve and improve the resource. The study quantified the commercially oriented smallholder cattle farmers' WTP for conservation and regeneration of rangelands and its influencing factors. A double-bounded contingent evaluation method was used to estimate farmers WTP for rangeland conservation and regeneration. Determinants of farmers' WTP were evaluated using a binary logistic regression model. A structured questionnaire was administered to all 101 commercially oriented beneficiaries of the Nguni cattle project in North West Province, South Africa, to collect data on their WTP for improving rangelands and the influencing factors. Majority of farmers (>80%) in the study area were willing to pay the initial bid price of ZAR165.00, with the estimated mean WTP being ZAR244.00 ha^{-1} $year^{-1}$ for improving rangelands. Just below half of the farmers were already conducting some rangeland conservation and restoration practices implying the possibility of introducing more programmes to improve rangelands ecosystems. The logistic regression results show that farmers' WTP responses were influenced by education ($p = 0.012$), most important breed ($p = 0.039$), farming experience ($p = 0.026$), goat ownership ($p = 0.022$), ecoregion ($p = 0.079$), and income from cattle sales ($p = 0.048$). These factors influencing farmers' WTP provide essential information for designing better policy options and strategies for improving rangelands. Overall, the results demonstrate that farmers had positive WTP for improving their rangelands. This highlights the potential of involving smallholder cattle farmers in implementing payment programs designed to improve rangeland ecosystems.

4.1 Introduction

Millions of people across the Southern African region and more than a billion people globally continue to draw livelihoods directly from natural ecosystems (Oldekop et al., 2020; Wisely et al., 2018). Agricultural ecosystems serve as recipients of terrestrial ecosystems and have since been recognized as vital to rural farming communities in the past half-century (Bani and Damnyag, 2017; Leroy et al., 2018). Because of the growing human population, particularly in Africa (Tsan et al., 2019) and with increased demand for food (Kotze and Rose, 2015), agroecosystems face more significant challenges than other ecosystems (Sooriyakumar et al., 2019). Therefore, the long-term sustainability of agroecosystems is essential at regional, national, and local levels, especially in Africa's drier countries like South Africa (Blignaut et al., 2008; Le Maitre et al., 2009). technology by the farmers because farmers have always relied on the government for new technologies. Therefore, it is important to note that the LMDS model is not being introduced as a substitute to the current public extension approach (technology transfer-based) but rather as a complementary initiative.

In South Africa, livestock contributes more than 50% of the value of agricultural production (DALRRD, 2019), with beef cattle farming being an important income diversification strategy for the industry and, most of all, the smallholder farmers. Over 40% of the country's cattle population is owned by subsistence and commercially oriented smallholder farmers (DALRRD, 2019), who raise the animals on private, leased, or communal rangelands (Bester et al., 2003; Mapiye et al., 2019). Rangelands are a significant part of the diverse feed resource base for cattle production in South Africa and the SSA region (Descheemaeker et al., 2016; Herrero et al., 2013; Mapiye et al., 2018). About 80% of South Africa's agricultural land (60% of the country's size) has remained suitable for extensive grazing (DALRRD, 2019; FAO, 2016). Briske (2017) defined rangelands as natural landscapes mainly unsuitable for crop cultivation, providing water and forage for animals. Rangelands are endowed with a great diversity of ecosystem goods and services which include provisioning of bulky and least costly livestock feed, acting as carbon sinks, balancing biodiversity, facilitating pollination and soil conservation, and stabilizing the climate (Bikila et al., 2016; Dutilly-diane et al., 2007; Ellery et al., 1995; Papagallo, 2018; Upton et al., 2015).

South Africa and many other developing countries experience a widespread depletion and destruction of rangeland ecosystems, especially in the arid and semi-arid cattle producing provinces such as North West (Le Maitre et al., 2009; Palmer and Bennett, 2013). Under low-input smallholder farming systems in South Africa’s provinces such as North-West, rangeland ecosystems are degenerating due to climate change and management problems, including high stocking rates, fires, uncontrolled invasive species (Kotze and Rose, 2015; Meissner et al., 2014), excessive continuous grazing, and lack of replenishment strategies (Kioko et al., 2012; Letsoalo, 2019). The excessive depletion of rangelands is further compounded by farmers' limited appreciation of the value of their ecosystem services (Letsoalo, 2019; Mukama, 2010). Therefore, the direct impacts to farmers are a decline in farm carrying capacity and huge costs of supplementary feeds (Taha and Khidr, 2011), which often reduce farm profitability and sustainability. Many studies (ITU, 2020; Kotze and Rose, 2015; O'Connor et al., 2011; Palmer and Bennett, 2013) recommend the importance of proper rangeland management and continuous replenishment to ensure sustainable farming systems.

In many emerging economies like South Africa, the government and various institutions have been introducing various strategies to protect and conserve ecosystem services in the past decade (Sherbut, 2012). Most activities seek to achieve sustainability in livestock production by balancing animal productivity and environmental protection (Lebacq et al., 2013). Payment for ecosystem services is one of the widely used strategies which continues to gain increased traction in South Africa and other emerging economies (Blignaut et al., 2008; Garbach et al., 2012; Le Maitre et al., 2009; Papagallo, 2018). The strategy is designed to incentivize landowners and communities to conserve natural ecosystems intact and restore degraded ecosystems services. Generally, payment for ecosystem services is estimated by eliciting the users' WTP for the ecosystem services consumed (Doğan et al., 2020; Nyongesa et al., 2016). Payment for ecosystem services is mainly used to mitigate climate change and mainstream the conservation of scarce water resources, woodlands and other endangered ecosystems (Garbach et al., 2012; Sherbut, 2012). With most existing payments for ecosystem services schemes, the government and concerned institutions pay the users for implementing measures to protect the ecosystems (Farley, 2012). However, payment for ecosystem services with farmers themselves paying has not been implemented under smallholder production systems to improve rangelands (Papagallo, 2018). Therefore, the current study estimates the commercially oriented smallholder cattle producers' WTP for regenerating their rangelands and the socio-economic factors determining their WTP. The farmer's WTP for improving rangeland ecosystems could relate to their WTP for new technologies such as the LMDS. Also, implementation of rangeland regeneration and conservation measures with farmers paying can be conducted through the LMDS platform.

4.2 Willingness to Pay for Ecosystem Services and achieving ecological sustainability in emerging economies

The potential contribution of sustainable agriculture in improving and maintaining the health of humans, livestock, and natural ecosystems has been well-documented. Since the past two decades, the sustainability concept is gradually becoming a high priority on the agenda of improving smallholder agricultural development systems (Hoffmann, 2011; Kotze and Rose, 2015; Marundure et al., 2018; Odunuyi et al., 2020). The concept was contextualised in a farm systems management and development perspective by the European Federation for Animal Science (EAAP) in 2015. According to EAAP (2015), sustainability is based on a commitment to continuous improvement, with performance gaps being identified and addressed while acknowledging the need to uphold an appropriate balance of the concept's three interdependent pillars. The three main pillars of sustainable agricultural systems are economic profitability, environmental health, and social development (Lebacq et al., 2013; Khwidzili and Worth, 2019). Sustainable smallholder cattle farming systems should optimise animal production and farm profits without deteriorating the ecosystem services provided by grazing rangelands. Developing the LMDS can incorporate the WTPs for ecosystem services. Farmers will be able to monitor and record their own rangeland status and share rangeland conservation practices with other farmers using the LMDS. It is important to note that the LMDS model is not being introduced as a substitute to the current public extension approach (technology transfer-based) but rather as a complementary initiative.

Invariably, natural rangelands are the primary production input for communal ruminant production systems (Meissner et al., 2013; Mapiye et al., 2018). Kotze and Rose (2015) and Marandure et al. (2018) note that rangelands produce grass-fed meat that is perceived to be much healthier than grain-fed meat and has become an essential component of cattle value-adding strategies. However, poor rangeland management practices such as excessive biomass depletion through overgrazing and overstocking have often pushed rangeland ecosystems to irreversible depletion levels, jeopardising farm systems' ecological sustainability (Kotze and Rose, 2015; RMRD SA, 2020). To maintain productivity, farmers use bought-in supplementary feeds that are costly and sometimes unavailable, especially under resource-constrained farming systems (Taha and Khidr, 2011).

Ecosystem service concepts have been widely mainstreamed into economic and socio-ecological decision-making by introducing innovative market-based conservation strategies like PES (Mukama, 2010; Nyongesa et al., 2016). So far, PES has attained substantial global recognition and attention as an alternative approach to improving human livelihoods and agroecosystem landscapes' sustainability (Cole, 2010; Aydogdu, 2019). In most existing case studies of developing countries, the payment for maintenance of ecosystems services which are inherently non-excludable, is typically made by parties representing the users or the government (Farley, 2012). However, the governments and public sector institutions have a lower capacity to fully pay for the protection of ecosystem services, especially on individually managed farms, due to financial insufficiency in public budgets (Pappagallo, 2018; Aydogdu, 2019). In that regard, the long-term perspective of ensuring the sustainability of rangeland ecosystems through effective management and PES should shift towards the inclusion of individual farmers (Dutilly-Diane et al., 2007; Broom et al., 2013; Sooriyakumar et al. 2019). Moreover, this can be achieved through a cost-sharing arrangement between the users (farmers) and the government or supporting institutions. Nowers et al. (2013) reported that low-input ruminant producers, especially those on communal land, have very little sense of stewardship of rangelands, which hinders their participation in ecosystem restoration. However, this hypothesis stands to be tested, especially with farmers on private farms and are transitioning from subsistence farming to commercial farming (Palmer and Bennett, 2013).

The PES schemes have been mainly implemented to support optimal watershed management, carbon sequestration, biodiversity conservation and general landscape restoration (Chesterman and Hope, 2012; Dorligsuren et al., 2015) with users receiving payments for conservation and protection of the resources (Farley, 2012). In South Africa, PES supported the Baviaanskloof programme, managed by South African National Biodiversity Institute (SANBI); Cape Action for People and the Environment (CAPE); Department of Water Affairs and Forestry; United Nations Development Programme and the World Bank (Chesterman and Hope, 2012). Some of the project activities for the Baviaanskloof programme include planting indigenous trees, removing alien species, promoting sustainable land use and vegetation restoration. One of the successful PES schemes is the 'Watershed agreements' in Bolivia, appropriated and adapted by 40 Bolivian municipalities. The scheme has changed the behaviour of about 200 000 people towards the conservation of watershed ecosystems. In that scheme, about 4500 upstream farmers conserved 210 000 ha of the forest that produces their water, while the downstream users (195 000) were paying them USD500, 000 every year to do so (Butler, 2012).

The monetary valuation of ecosystem services based on an estimate of WTP is one of the prevalent economic perspectives used to achieve the PES and ensure optimum use of natural resources (Mukama, 2010; Farley, 2012; Dogan et al., 2020). As a general assumption, farmers are likely to pay or accept payment for waiving unsustainable conventional farming practices when they believe that new sustainable practices will increase farm productivity and enhance agroecosystem performance. (Nyongesa et al., 2016).

A research study conducted by Ning et al. (2019) in Inner Mongolia of China found that respondents' WTP for protection of grassland ecosystems was USD25.11, and the WTP was significantly determined by their age, education, and household income. Aydogdu (2019) conducted a study to evaluate farmers' WTP for sustainable water and soil resources in Sanliurfa, Turkey. About 40% of the respondents had a positive WTP determined as much as USD48.8/ha. Their decisions to pay were largely influenced by farmers' location, availability of household manpower, land size, farm ownership status, and the income derived from agriculture (Aydogdu, 2019). For research on livestock farmers' willingness to improve rangeland sustainability, one of the few initiatives available include PlanVivo in Mongolia (Dorligsuren et al., 2015). It is one of the first and most relevant PES programs to sustain rangelands. It involves more than 200 herder households who are expected to sequester 100,000t of carbon on 77,000 hectares through improved grazing management practices (Dorligsuren et al., 2015).

In a study by Pappagallo (2018), the practicalities of operationalising PES in Africa's pastoralist and agro-pastoralist rangeland production systems were noted. However, PES has not been widely used to protect grazing lands, especially by giving the responsibility of paying to farmers (Pappagallo, 2018). According to Aydogdu (2019), using the WTP principle based on the solvency of the users (farmers) could protect grazing landscapes while improving the farmers' livelihoods. In eliciting smallholder farmers' WTP for various natural ecosystem resources and their conservation, Contingent Valuation was the most preferred approach in many research studies (Nyongesa et al., 2016, Shee et al., 2019). The LMDS can be used as a tool to include rangeland conservation and so encourage farmers to share knowledge on rangeland practices. The agricultural extension officers should be able to use the platform to share information and practices of improving rangelands with farmers.

4.3 Materials and Methods

4.3.1 Description of study site

The study was carried out in the North-West Province (26.6639° S and 25.2838° E) of South Africa (Figure 4.1). The province covers 116 320 square kilometres and occupies 9.5% of the total land area of South Africa. The province is divided into four district municipalities subdivided into 18 local municipalities (Table 4.1). There are two major biomes in the North-West Province: Grassland and the Savanna biomes

(Daemane et al., 2010), consisting of flat landscapes with scattered trees and grasslands (Desmet et al., 2009). It is characteristic of quintessential Africa and forms part of the southern Kalahari Desert. The province's rangeland ecozones (Table 4.1) are primarily sweet veld covering the half-southern and extreme northern parts of the province and a strip of sour veld cutting through the centre. Approximately 57% of the province's land is considered suitable for grazing, and cattle farming is the main livestock enterprise. About 28% of the land is regarded as potentially arable, with maize and sunflower being the most important crops.

The province's temperatures range from 17° to 31°, in the summer and 3° to 21° in the winter. Average annual rainfall totals about 360mm, with almost all of it falling during summer between October and April. Figure 4.1 shows the map of South Africa with North-West and the province's district and local municipalities.

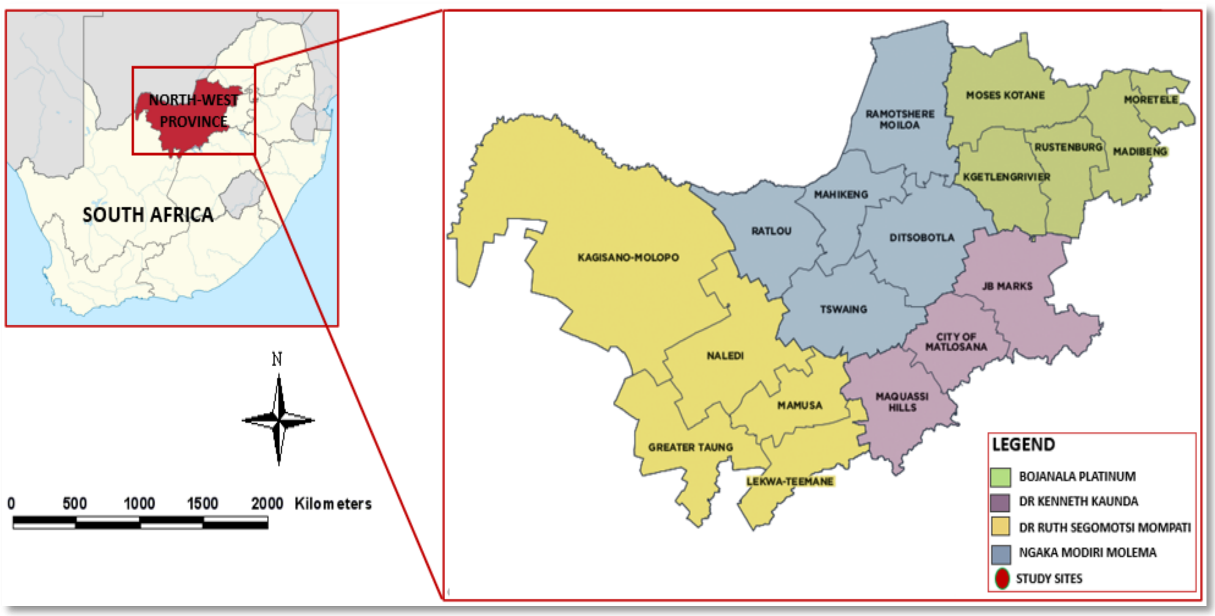

Figure 4. 1 The map of North-West province and its local municipalities

4.3.2 Selection of respondents

The study population comprised commercially oriented smallholder cattle producers who are beneficiaries of the North-West IDC-Nguni cattle programme. The survey sample was composed of all 101 farmers (census approach) actively participating in the programme since its introduction in the province. Table 4.1 demonstrates the distribution of the farmers, pedo-climatic conditions and rangeland ecozones across the province.

Table 4. 1 Pedo-climatic conditions, ecozones, and the distribution of farmers across the districts of North West province, South Africa

District Municipalities	Mean Annual Temperature (°C)	Mean Annual Rainfall (mm)	Altitude (m)	Soil Types	Vegetation types	Local Municipalities	No/ of Farmers	Rangeland Ecozones
Dr Ruth Segomotsi Mompati	11.6-26.6	397	869-2062	Kalahari sand Brown & Red Ferrallitic	Bushveld Thornveld Vaalbosveld Grassland	Greater Taung	1	Sweet
						Kagisano-Molopo	22	Sweet
						Naledi	2	Sweet
Ngaka Modiri Molema	11.8-26.0	447	926-1729	Kalahari sand Brown & Red Ferrallitic Black clays	Grassland Bushveld Thornveld	Ditsobotla	1	Sour
						Mahikeng	11	Sour
						Ramotshere Moiloa	3	Sweet
						Ratlou	1	Sour
						Tswaing	5	Sour
Dr Kenneth Kaunda	11.5-25.3	512	1096-1833	Aeolin Sandy Brown & Red Ferrallitic Highveld Prairie	Woodland Grassland Sourveld	Matlosana	7	Sweet
						JB Marks	18	Sour
						Maquassi Hills	1	Sweet
Bojanala Platinum	14.0-27.5	508	833-2038	Black clays Brown & Red Ferrallitic Grey Ferruginous Lateritic	Bushveld Thornveld Woodland	Kgetleng river	8	Sweet
						Madibeng	8	Sweet
						Moretele	2	Mixed
						Moses Kotane	7	Sweet
						Rustenburg	4	Sweet

4.3.3 Overview of the North West IDC-Nguni cattle project

Commercially oriented smallholder farmers under the North west-IDC Nguni cattle programme are part of the beneficiaries of the government's Land Redistribution for Agricultural Development (LRAD) programme (Ortmann and Machethe, 2003; MacLeod *et al.,* 2010). The majority of these are black farmers who are currently transitioning from small commercial to large commercial scale. The majority of these farmers continue to be confronted by many systemic challenges and constraints identified in many studies (Mapiye et al., 2018; Khapayi and Celliers et al., 2016; Malusi et al., 2021).

The North west-IDC Nguni cattle programme is currently a 1-year development orientated partnership between the North-West University (NWU), IDC and North West DALRRD. Launched in 2007, the project aims to empower subsistence farmers with livestock farming skills and develop their entrepreneurial aptitude to elevate the farming, indigenous genetic resources such as the Nguni cattle. Unlike other breeds of cattle, this indigenous breed is known for its high fertility rate and ability to withstand harsh conditions and livestock diseases, making it well suited to the climate of the North West Province.

To be eligible for the project, one has to be from the previously disadvantaged category, having fenced land with sufficient grazing (at least 700ha), water and carrying capacity for at least 60 cattle. Beneficiaries receive 24 Nguni cattle, consisting of 23 heifers and one bull, all of which have been immunized against tuberculosis and heartwater. In addition, farmers receive a starter pack of medicines for calves.

The farmers are then given five years to grow the herd and, during this time, receive support from a full-time project manager. After five years, repayment is made to the board of trustees in 12 young Nguni cattle (11 heifers and one bull). The board of trustees then redistributes the cattle to new beneficiaries. This ensures sustainability and empowerment of more and more upcoming farmers to become commercial farmers. The NWU and the Taung and Potchefstroom colleges of agriculture provide basic training in veld and beef cattle management, and the farmers are also taught about diseases such as tuberculosis, brucellosis and heartwater.

4.3.3 Data collection

4.3.3.1 Survey

A structured questionnaire (Human ethical clearance: SU project number 9293) was developed, pre-tested and administered to collect quantitative data from individual farmers through face-to-face interviews between November 2020 and February 2021. Five enumerators were recruited and trained to assist in administering the questionnaire. The questionnaire, designed in English, was translated to Setswana (local language) during interviews for easier and comfortable farmer responses. The farmers' socio-economic and farm characteristics were captured. Data on cattle numbers and farm performance, general conditions of rangelands, causes of rangelands degradation and rangeland regeneration practices by the farmers were captured. Personal observations were used to record the respondents' non-verbal cues and to observe some important rangeland regeneration practices by the farmers in the study area.

4.3.3.1.1 The contingent Valuation Method

Contingent Valuation was used in this study to elicit information about respondents' WTP for improved rangelands. The dichotomous choice approach has two procedures: the single-bounded and the double-bounded dichotomous choice methods. There is the single-bounded dichotomous choice method introduced by Bishop and Heberlein (1979), in which the respondents can be offered a bid price and asked their WTP for that amount. This approach, however, needs large samples of respondents for the WTP estimation to be deemed significant. Hanemann et al. (1991) developed a double-bounded dichotomous choice CV method to avoid this problem, which uses a follow-up question giving an alternative bid price higher or lower than the initial bid price. The model's response option is dichotomous, requiring a "Yes" or "No" answer (Hanemann et al., 1991). Thus, the alternative bid price can be higher if the response to the first bid price is affirmative and lower if otherwise (Lopez-Feldman, 2012). The double-bounded dichotomous choice CV has been proven to be asymptotically more efficient and allows smaller samples to give accurate WTP estimations (Lopez-Feldman, 2012; Shee et al., 2020) and can correct the upward or downward bias that comes with poor identification of the initial bid price (Hanemann et al., 1991). This model has been applied in many studies (Hanemann et al., 1991; Nyongesa et al., 2016; Shee et al., 2020) and was used in the current study.

The standard model structure of the CV section on the questionnaire first provided a hypothetical scenario describing the importance of rangelands and the need to constantly restore them to improve the farm system's environmental sustainability. The second part of the model was composed of elicitation questions asking farmers' WTP or setting aside a certain amount of money ha^{-1} year^{-1} for the regeneration of rangelands. An initial minimum bid price of ZAR165.00 was offered, and if the respondent answers "Yes", a higher bid price of ZAR250.00 was offered and if the response to the initial bid is "No", a lower bid price of USD85.00 was offered. A realistic initial bid price used for the study was based on recommendations from an experiment conducted by du Pisanie (2019) at Stockfarm in Northern Cape, South Africa and from the questionnaire pre-testing exercise. For a follow-up question to be valid, the follow-up bid must be significantly different from the initial bid, as suggested by (Vercueil, 2000). Therefore, the initial bid price was reduced or increased by 50% to have the lower and higher bids, respectively. Four response outcomes were derived (yes-yes, yes-no, no-no, no-yes). Given that $\mathbf{t_1}$ is the first bid price and $\mathbf{t_2}$ to be the second, following Lopez-Feldman (2012), the bounds on WTP for each respondent's response would then be in one of the following four outcome groups:

a) Yes-no: *the respondent is willing to pay the first bid price and not the second price* $(t^1 \leq WTP < t^2)$.
b) Yes-yes: *the respondent is willing to pay both the first and second bid prices* $(t^2 \leq WTP < \infty)$.
c) No-yes: *the respondent is not willing to pay the first bid price but the second price* $(t^2 \leq WTP < t^1)$.
d) No-no: *the respondent is not willing to pay both the first and second bid prices* $(0 < WTP < t^2)$.

4.3.4 Statistical analysis

Quantitative data were analysed using Statistical Analysis System (SAS) v. 9.4 (SAS Institute, 2012) and Stata/SE 16 (StataCorp, 2019). Data on farmers' demographic profiles and farm information, farm rangeland conditions, grazing systems and rangeland management practices were subjected to descriptive statistics using the PROC FREQ procedure of SAS.

This study employed a bivariate probit model for estimating WTP for regenerating rangelands from the data collected through the double-bound dichotomous elicitation method. The bivariate probit model is a general parametric model of two-response surveys (Haab and McConnell, 2013). The double-bound data, including two price bids, were used to estimate the mean WTP for regenerating rangelands. Following Haab and McConnell (2013), the general econometric model for the double-bounded data comes from the formulation:

$$WTP_{ij} = \mu_i + \varepsilon_{ij}$$

Where WTP_{ij} represents the j_{th} respondent's WTP for regenerating rangelands, and i = 1, 2 represents the first and second answers. The μ_1 and μ_2 represent means for the first and second responses. This general model incorporates the idea that, for an individual, the first and second responses to the contingent valuation questions are different, perhaps motivated by different covariates and perhaps by the same covariates. Therefore, the likelihood functions below were constructed from the probabilities of observing each of the possible two-bid response sequences (yes-no, yes-yes, no-yes, no-no) based on Kidane et al. (2019).

$$Pr\,(yes, no) = Pr(WTP_{1j} > t^1, WTP_{2j} < t^2)$$
$$Pr\,(yes, no) = Pr(\mu_1 + \varepsilon_{1j} \geq t^1, \mu_2 + \varepsilon_{2j} < t^2) \quad (I)$$
$$Pr\,(yes, yes) = Pr(WTP_{1j} > t^1, WTP_{2j} \geq t^2)$$
$$Pr\,(yes, yes) = Pr(\mu_1 + \varepsilon_{1j} > t^1, \mu_2 + \varepsilon_{2j} \geq t^2) \quad (II)$$
$$Pr\,(no, yes) = Pr(WTP_{1j} < t^1, WTP_{2j} \geq t^2)$$
$$Pr\,(no, yes) = Pr(\mu_1 + \varepsilon_{1j} < t^1, \mu_2 + \varepsilon_{2j} \geq t^2) \quad (III)$$
$$Pr\,(no, no) = Pr(WTP_{1j} < t^1, WTP_{2j} < t^2)$$
$$Pr\,(no, no) = Pr(\mu_1 + \varepsilon_{1j} < t^1, \mu_2 + \varepsilon_{2j} < t^2) \quad (IV)$$

Then, the $\mathbf{j^{th}}$ contribution to the likelihood function becomes:

$$L_j(\mu/t) = (I)^{YN}\mathrm{x}(II)^{YY}\mathrm{x}(III)^{NY}\mathrm{x}(IV)^{NN} \qquad \text{(ii)}$$

Where t^1 and t^2 are first and second bid prices and I, II, III and IV refer to the probability equations given above. YN=1 for yes-no answer, 0 otherwise; YY=1 for the yes-yes answer, 0 otherwise; NY=1 for no-yes answer, 0 otherwise; NN=1 for no-no answer, 0 otherwise. In the model, error terms are assumed to be normally distributed with mean zero and respective variances of σ_1^2 and σ_2^2 and therefore the WTP_{1j} and WTP_{2j} have a bivariate normal distribution with means μ_1 and μ_2, variances $\sigma^2{}_1$ and $\sigma^2{}_2$ and correlation coefficient.

Given the dichotomous responses to each question, the normally distributed model is represented as a bivariate probit model. Each respondent’s contribution to the bivariate probit likelihood function can be shown as given by Haab and McConnell (2013):

$$L_j(\mu/t) = \Phi\varepsilon_1\varepsilon_2, (d_{1j}\left(\frac{t^1-\mu_1}{\sigma_1}\right)' \, d_{2j}\left(\frac{t^2-\mu_2}{\sigma_2}\right), d_{1j}d_{2j}\sigma \qquad \text{(iii)}$$

Where, $\varepsilon_1\varepsilon_2$ is the standardized bivariate normal cumulative distribution function with zero means, unit variances and correlation coefficient $\boldsymbol{p}$. Defining $\mathbf{y}_{1j} = \mathbf{1}$ if the response to the first question is yes, and 0 if otherwise; $\boldsymbol{y_{2j}} = \mathbf{1}$ if the response to the second question is yes, and 0 if otherwise; $\boldsymbol{d_{1j}} = \mathbf{2}\boldsymbol{y_{1j}} - \mathbf{1}$, and $\boldsymbol{d_{2j}} = \mathbf{2}\boldsymbol{y_{2j}} - \mathbf{1}$.

If the WTP is normally distributed and estimating the model through the maximum likelihood estimation method, the mean WTP for regenerating rangelands was determined following Haab and McConnell (2013) and used in a study by Kidane et al. (2019).

$$\boldsymbol{MWTP} = -\,{}^{\boldsymbol{\alpha}}/_{\boldsymbol{\beta}} \qquad \text{(iv)}$$

Where *MWTP* is the mean WTP for regenerating rangelands, α is the intercept of the estimated model and $\boldsymbol{\beta}$ is the coefficient of the bid values.

A binary logistic regression model was used to elicit the factors which influenced the WTP for rangeland ecosystem services. Table 4.2 describes the dependent and explanatory variables used in the logit model. Logistic regression uses the logit transformation to linearise the non-linear relationship between **X** (independent) and the probability of **Y** (dependent). It does this using odds and logarithms. Following Wooldridge (2012), the empirical model for the linear relationship between X and the log odds was specified as follows:

Logged odds: $\boldsymbol{Ln}\left(\frac{P_i}{1-P_i}\right) = \boldsymbol{\beta_0} + \boldsymbol{\beta_i X_i} + \mu_i \qquad (1)$

Where $\boldsymbol{i}$ refers to a given respondent; $\boldsymbol{\beta i}$ represents parameters that determine WTP for the initial bid; $\boldsymbol{P_i}$ is the probability that the $\boldsymbol{i^{th}}$ respondent will be willing to pay for the given bid; $\boldsymbol{X_i}$ represents factors to be assessed and $\boldsymbol{Ln}\left(\frac{P_i}{1-P_i}\right)$ is the log odds ratio in favour of WTP to pay for the initially offered bid price. The actual model used for estimation was:

$$\boldsymbol{Logit}(Y) = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 X_1} + \boldsymbol{\beta_2 X_2} + \boldsymbol{\beta_3 X_3} + \ldots.\boldsymbol{\beta_{12} X_{11}} + \mu_i \qquad \textbf{(2)}$$

$$\begin{aligned}\boldsymbol{Logit(WTP)} = {} & \boldsymbol{\beta_0} + \boldsymbol{\beta_1 Gender} + \boldsymbol{\beta_2 Education} + \boldsymbol{\beta_3 MaritalStatus} \\ & + \boldsymbol{\beta_4 Breed} + \boldsymbol{\beta_5 FarmingExperience} + \boldsymbol{\beta_6 farmSize} + \boldsymbol{\beta_7\ HerdSize} \\ & + \boldsymbol{\beta_8 GoatOwnership} + \boldsymbol{\beta_9 RangelandEcozone} + \boldsymbol{\beta_{10} Income} + \mu_i\end{aligned}$$

Table 4. 2 Explanatory variables fitted in model to determine WTP for improving rangelands by the commercially oriented beef cattle farmers

Explanatory Variable	Description of explanatory variables
Gender (X_1)	Gender of the farmer (Dichotomous, 1= male, 0= otherwise). Many studies (Bani and Damnyag, 2017; Gosbert et al., 2019) have established that, male farmers have better access to means of production and income, and they are knowledgeable and experienced than females. Therefore, male farmers are hypothesized to have a higher WTP for improving rangelands than women.
Education level (X_2)	Farmer's education level (Dichotomous, 1 = more educated [at least Matric qualification], 2 = less educated). Education enhances farmers' productivity efficiency and promotes a more positive attitude and understanding towards payment for ecosystem services (Asrat et al., 2004; Ning et al., 2019; Pender and Kerr, 1998; Sooriyakumar et al., 2019). Therefore, more educated farmers are likely to have higher WTP for improving rangelands than less educated farmers.
Marital status (X_3)	Farmer's marital status (Dichotomous, 1= married, 0= Otherwise). The studies carried out by Lalika et al. (2017) and Zaiton et al. (2019) show that marital status plays an important part in WTP. According to Zaiton et al. (2019), married people conserve resources to benefit their children and future generations. Subsequently, married farmers are expected to have higher WTP than unmarried farmers.
Cattle Breed (X_4)	The most important cattle breed at the farm (Dichotomous, 1= Nguni, 0= Otherwise). Generally, cattle breed type is anticipated to influence farmers' demand for rangelands. Indigenous cattle breeds are adapted to local conditions (Bester et al., 2003; Sambo, 2020) and can produce high-quality products under natural rangelands in smallholder farming systems (Mapiye et al., 2019). Therefore, farmers indicating Nguni as the most important breed are likely to have a higher WTP for improving rangelands than farmers with cross-breeds and exotic breeds.
Farming experience (X_5)	Farmer's experience level in farming (Dichotomous, 1= High experience [above mean], 0= Low experience/otherwise). Long tenure gives the farmers more practical knowledge of their farms and an appreciation of the need to conserve natural resources (Uddin et al., 2016). It is, therefore, anticipated to determine farmers' WTP positively.
Farm Size (X_6)	Size of farms owned by farmers (Dichotomous, 1=Large [above 700ha], 0=Small/otherwise). Farm size is often perceived to correlate positively with farmers' economic viability and often encourages farmers to practice new technologies, thus potentially increasing their WTP to improve rangelands (Asrat et al., 2004). On the other hand, farmers with large farms might not be willing to pay for these conservation activities because their grazing resources are adequate, implying a decrease in their WTP to improve rangelands.
Herd size (X_7)	The size of cattle herds owned by farmers (Dichotomous, 1=Large [Above mean herd size], 0=Small/otherwise). Farmers with large herd sizes are likely to produce more animals suggesting high income and high demand for rangelands (Foti et al., 2007; Pender and Kerr, 1998)(Foti et al., 2007; Pender and Kerr, 1998). Therefore, farmers with large herd sizes are expected to have a higher WTP than farmers with smaller herd sizes.
Goat Ownership (X_8)	Goat ownership by farmers (Dichotomous, 1= Yes, 0= No). In addition to having cattle, owning goats at the farm places more pressure on rangelands rendering the farmers vulnerable to feed shortages. Therefore, goat ownership is hypothesized to increase farmers' WTP for improving rangelands.
Rangeland ecozone (X_{10})	Rangeland type occupied by the farmer (Dichotomous, 1=Sweet rangeland ecozone, 0=Otherwise). The productivity of cattle raised on rangelands depends on the type and quality of rangelands. Sweet rangelands ecozones are more preferred than sour rangeland ecozones due to their high quality (Ellery et al., 1995; Nqeno et al., 2011). Therefore, farmers on sweet rangelands are expected to have lower WTP for improving rangelands than those on sour rangelands.
Annual income (X_{11})	Annual income from cattle sales (Dichotomous, 1= higher income [above mean], 0= low income/otherwise). Income from livestock sales increases farmers' financial capacity to protect natural resources (Doğan et al., 2020; Foti et al., 2007; Nyongesa et al., 2016). It is, therefore, anticipated to influence farmers' decisions to pay for improving rangelands positively.

4.4 Results

4.4.1 Farmers' socio-economic characteristics

Table 4.3 profiles the respondents' socio-economic characteristics. The results show that beef cattle farming was dominated by male farmers (74% of respondents). Most respondents were married (65%), between 35 and 64 years (65%) and had 3 to 5 members. Seventy per cent of the respondents had at least secondary education. A large proportion (95% of respondents) were full-time farmers, and the average farming experience was 19 years. Over 60% of the experienced farmers (above 39 years) were based in the sweet rangeland ecozones. Eighty-two per cent ranked livestock farming as their main source of income.

Table 4. 3 Characteristics of the commercially oriented beef cattle farmers in North-West province, South Africa

Variable	Category	Per cent
Gender	Female	26
	Male	74
Marital Status	Married	65
	Single	21
	Divorced/widowed	14
Household sizes	Below 3	15
	3-5	44
	6-8	34
	Above 8	7
Farmer's Age (years)	35 and below	6
	35-44	21
	45-54	23
	55-64	24
	Above 64	26
Farmer's highest education level	No formal education	3
	Primary education	28
	Lower Secondary	8
	Upper secondary	32
	Post-secondary/Technical education	18
	Higher tertiary education	11
Farming engagement/employment	Full-time farmer	95
	Part-time farmer	5

4.4.2 Farm sizes, farmland ownership status and access to formal livestock training of farmers

Figure 4.2 presents the farm sizes owned and rangeland sizes utilized for livestock grazing by farmers in the study area. Majority of respondents had total farm (45%), and rangeland (47%) sizes between

300 and 799 ha (Figure 4.2). About 87% of the farms were leased from the government, with the remainder being privately owned (11%). The average size of the farms within the surveyed area was 952 hectares, with the smallest farm and largest farm being 110 and 3119 hectares, respectively. Most large farms (over 70%) were located within sweet rangeland ecozones. Majority of respondents (70%) used less than 800ha of rangelands for cattle grazing (Figure 4.2), with the average rangeland size being 772ha. The study also found that nearly two-thirds of the farmers had formal livestock training (68%) acquired from various institutions and through farmer support programs.

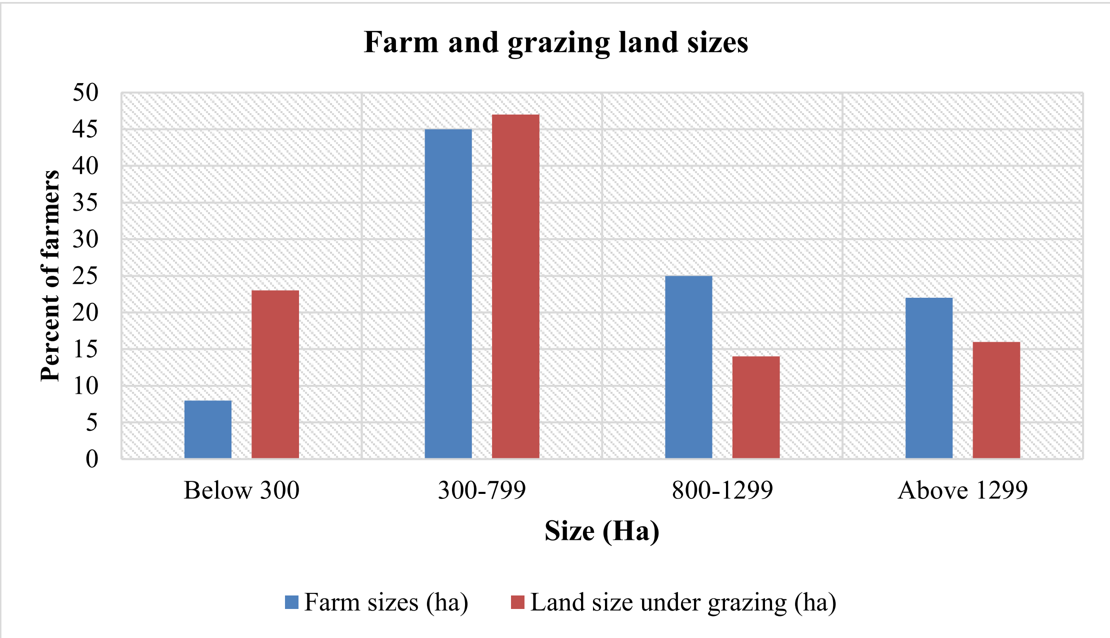

Figure 4. 2 Distribution of farmers according to their total farm sizes and land sizes under grazing.

4.4.3 Livestock species characterisation and herd sizes among farmers

Figure 4.3 summarises total livestock species numbers among the farmers. Majority of farmers had cattle herd sizes between 79-129 and the Nguni herd sizes between 30 and 79 (Figure 4.3). The cattle herd size averaged 103, while the Nguni herd averaged 63. Respondents occupying most of the large farms (>1299) had also large cattle herd sizes (>129) (Figure 4.3). Cattle were rated (93% of respondents) as the most important species, followed by chickens (4%) and goats (2%). Ninety-four per cent of farmers kept Nguni cattle, and majority of them (62%) considered it as the most important breed, followed by Bonsmara (57%), mixed (37%), as well as Brahman (21%). Eighty per cent of the respondents reported that their cattle were in good body condition. In the past calving season (2019-2020), the studied farmers received an average of 45 calves, with 94% of them achieving a 12-month calving interval.

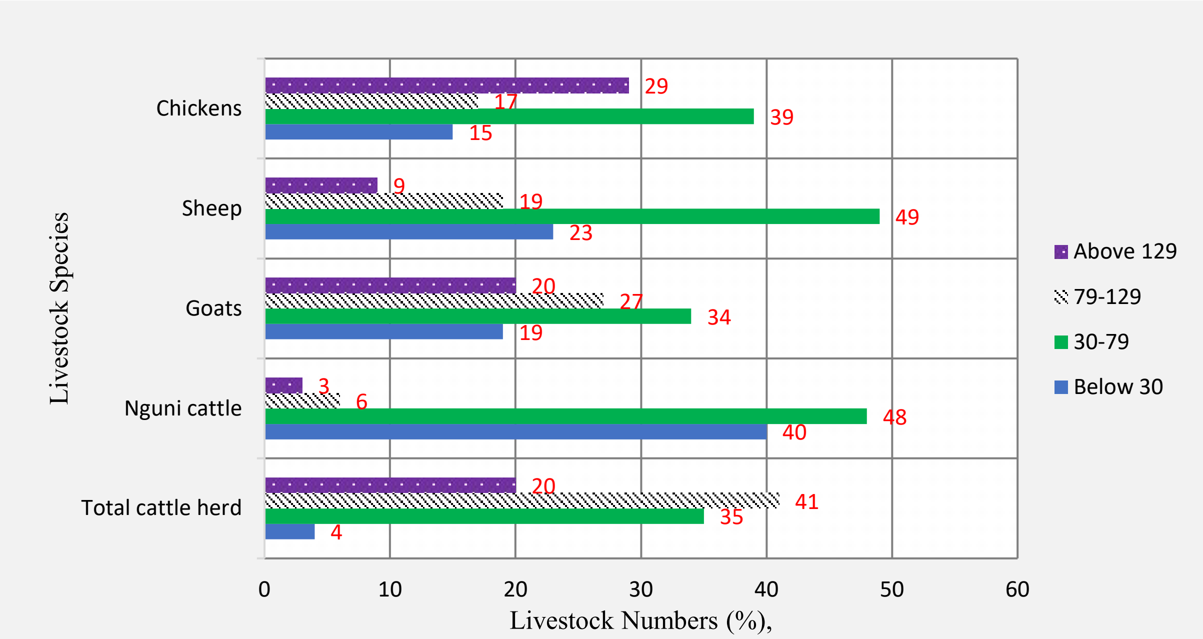

Figure 4. 3 The distribution of livestock numbers among farmers

4.4.4 Farm rangeland conditions, challenges and management strategies

The primary cattle feed source for all respondents was natural grazing obtained from the rangelands, although some farmers supplemented their cattle with bought-in feeds (66% of respondents) and farm by-products (29%). Rotational grazing was the predominant grazing system among respondents (86%), with only 14% practising continuous grazing. A greater proportion (over 60% of respondents) reported the general conditions of their rangelands as good, whereas 19% indicated they were poor to very poor. Of those who reported poor to very poor (n=20), they indicated that the poor state of their rangeland ecosystems was compounded by the presence of invasive species (58% of respondents), overgrazing (38%), dry conditions (21%), land degradation (13%), fires (8%) and lack of grazing camps (21%). To improve the condition of rangelands, less than 50% of farmers indicated that they were conducting some rangeland conservation and restoration practices on their farms. The rangeland management practices conducted by farmers were planting new trees and pastures (22%), removing invasive and unwanted trees (20%), application of manure and fertilizer (9%) and resting bigger portions of the farms (70%)

as their strategies. Boreholes were the main source of water (86% of respondents), followed by dams (8%) and rivers (6%). Most of the farmers indicated they have a good supply of drinking water for their animals.

4.4.5 WTP for rangeland regeneration by commercially oriented smallholder cattle farmers

Regarding farmers' WTP for improving rangelands, an initial bid price of ZAR165 was offered to all farmers during interviews, and Table 4.4 summarises responses for this price and the follow-up bid prices offered. About 83% of the farmers were willing to pay the initially offered bid price. The findings show that over 70% of respondents were willing to pay both initial and the following bid prices *"Yes-Yes"* (Table 4.4). Majority of those willing to pay had at least secondary education (60%), were males (74%), above the age of 45 years (71%) and were earning between ZAR30, 000.00 and 170, 000.00 annually from cattle sales (62%). Based on the probit model analysis results, the mean WTP of the respondents was estimated to be USD250.00 ha^{-1} year^{-1}.

Table 4. 4 Summary of the offered initial and follow up bid prices and the responses

Sets of Bids	Initial Bid (t^1)	Higher Bid ($t^2/y_1 = 0$)	Lower Bid ($t^2/y_1 = 0$)
(ZAR)	165.00	250.00	85.00

Responses	*Yes, to initial bid*	*Yes-Yes*	*Yes-No*	*No-No*	*No-Yes*
No. of observations (%)	83	72	10	14	4

4.4.6 Determinants of farmers' WTP for rangeland conservation and regeneration

Table 4.5 displays the logistic regression estimates for factors hypothesized to influence farmers' WTP for the conservation and regeneration of rangelands. Among the ten selected explanatory variables, education level, most important cattle breed, farming experience, keeping goats and income from cattle sales had a significant effect on farmers' WTP for the conservation and regeneration of rangelands. Thus, based on the regression model results (Table 4.5), an education level ($p = 0.012$) had a positive and significant influence on farmers' WTP, implying that highly educated farmers were more likely to pay than less educated farmers. Farmers who identified Nguni as the most important cattle breed ($p = 0.039$) were more likely to agree to pay than those valuing other breeds. The findings also indicate that livestock farming experience (p = 0.026) had a positive and significant influence at a 1% level in relation to the respondents' WTP. Moreover, respondents who reported that they own goats apart from cattle had a higher WTP (p = 0.022) than those who did not own goats. Farmers located within sweet rangeland ecozones had a lower WTP (p = 0.079) for rangeland improvement than those within sour rangeland ecozones. Income from cattle sales also had a positive and significant effect on farmers WTP (p = 0.048) at a 5% level. Thus, farmers with higher income were likely to pay for rangeland conservation and regeneration than those with less income. Conversely, the logistic regression results (Table 4.5) indicate that the influence on respondents' WTP of factors such as farm size, gender, marital status, and cattle herd size was not significant (p > 0.05).

Table 4. 5 Binary Logistic regression results for factors influencing farmers' WTP

Variables	**Coef. Estimate (β)**	**Std. E**	**p-value**	**Significance**
Gender	-0.587	1.023	0.536	NS
Education level	3.271	1.301	0.012	**
Marital status	1.391	0.941	0.139	NS
Most Important cattle breed	2.024	0.940	0.031	**
Farming experience	2.468	1.108	0.026	**
Farm size	1.061	1.088	0.329	NS
Cattle herd size	0.760	1.123	0.498	NS
Goat Ownership	3.072	1.341	0.022	**
Rangeland ecozone	-1.821	1.036	0.079	*
Sales Income	2.806	1.418	0.048	**

Note: ***, **, * Statistical significance at 1% (p<0.01), 5% (p<0.05), 10% (p<0.10), respectively

4.4 Discussion

The finding that most commercially oriented farmers were willing to pay for the conservation and regeneration of rangelands suggest that they might better understand the importance of ecosystem services payments. According to Letsoalo (2019), this could help them rehabilitate their rangelands. The observed WTP estimates relate to previous studies to stimulate users' WTP to protect and improve natural ecosystems (Doğan et al., 2020; Mukama, 2010; Ning et al., 2019; Upton et al., 2015). Xiong et al. (2018) found that about three-quarters of respondents had positive WTP, while Mukama (2010) and Kidane et al. (2019) found that two-thirds and over 50% of respondents were willing to pay the first bid for improved rangelands and irrigation water, respectively. However, Asrat et al. (2004) reported that more than 70% of respondents were unwilling to pay for soil conservation practices. Doğan et al. (2020) in the GAP-Harran Plain in Turkey, also, found that only 22% of the farmers had positive WTP, with over 40% of those who did not have WTP believing that the services should be free. Low WTP, especially within smallholder farming systems, could be driven by the fact that most farmers are resource-poor and believe that public sectors or donors are responsible for the payments (Doğan et al., 2020). The current high WTP reported by farmers may be attributed to increased awareness and demand for the provisioning, regulating, and cultural ecosystem services from rangelands (Yahdjian et al., 2015). Rangelands are increasingly perceived to be advantageous in terms of animal welfare (Temple and Manteca, 2020) and produce healthy beef with higher market value than intensive systems (Dutilly-diane et al., 2007; Kotze and Rose, 2015); hence farmers have high regard for the resource. The farmers' WTP for conservation and rehabilitation of rangeland ecosystem services implies the possibility of introducing payment for ecosystem services schemes under smallholder livestock systems where the resources are under constant threat (Le Maitre et al., 2009; Palmer and Bennett, 2013).

The finding that higher education achievement increased farmers' WTP for the conservation and regeneration of rangelands is consistent with the literature (Asrat et al., 2004; Ning et al., 2019; Pender and Kerr, 1998; Sooriyakumar et al., 2019). According to Asrat et al. (2004), education has a positive role in farmers' decisions to pay for conserving resources. The positive effect of education on WTP in the current study could be associated with improved human capital since the majority of farmers were educated. Thus, many studies (Mukama, 2010; Ning et al., 2019; Ouédraogo et al., 2018) acknowledges that educated farmers have high production and marketing efficiency, understands better and embrace new technologies and can make scientifically oriented decisions, including the need to invest in improving their rangelands compared to less educated farmers. In that regard, improving farmers' education could help improve their environmental stewardship and promote the ecological sustainability of commercially oriented farming systems (Aladi and Olujobi, 2014; Danquah and Kuwornu, 2015; Pender and Kerr, 1998). However, contrary to the current finding, an earlier observation by Mukama (2010) showed that more educated farmers were less likely to pay for improved rangelands than less educated farmers. One plausible explanation for this could be that more educated farmers may have better access to formal credit facilities (Fonta et al., 2018), which they could use to purchase supplemental feeds, thus reducing their reliance on communal rangelands.

Local cattle breed with adaptive attributes such as Ngunis are dominant under rangeland-based commercially oriented private farms and have high efficiency in utilizing low-quality feed resources that characterize rangelands (Bester et al., 2003; Mapiye et al., 2019; Sambo, 2020). On the contrary, communal smallholder farmers owned non-descript crossbreds and exotic breeds, which are less adapted to their local conditions (Malusi et al., 2021; Nqeno et al., 2011). This corroborates current findings showing that farmers who indicated Nguni as the most important breed were more likely to pay for rangeland improvements. Therefore, the higher WTP for improving rangelands by farmers with the Nguni breed is ascribed to the breed's adaptability to local conditions and high efficiency in utilizing low-quality feed resources that characterize rangelands ecozones in the arid to semi-arid conditions. As observed by the current study, some farmers cited replacing the Nguni breed with Bonsmara or crossing it with other breeds, such as Simbra, Brahman and Tuli. Sambo (2020) also observed this, who reported that the Nguni breed is under threat of diminishing as farmers prefer exotic breeds. Studied farmers indicated that Nguni cattle performed poorly in feedlots and have lower market value (Malusi et al.,. 2021) than other breeds such as Bonsmaras, explaining why they are replacing them.

The WTP for improved rangelands by farmers was positively determined by the farmers' level of farming experience. As indicated in Uddin et al. (2016), the observed positive WTP is attributable to long tenure, which gives the farmers experience and more practical knowledge about their farm resources and environment, translating into higher WTP for rehabilitating such resources. The result that farming experience positively impacted WTP for conservation of rangeland ecosystems contrasted with a previous study by Doğan et al. (2020), which found that experienced farmers (>30 years) had less WTP than those with less experience. This could be explained by the fact that since more experienced farmers are old farmers, they are less reliant on new technologies and information than young and new farmers hence the low WTP.

The current study correctly predicted that income from cattle sales had an affirmative and significant influence on farmers' WTP for rangeland conservation and regeneration. Similarly, (Xiong et al. (2018) and Doğan et al. (2020) found a positive relationship between farmers' annual incomes and WTP for improving water quality and sustainable agricultural activities. This could be because the farmers obtained incomes from cattle sales, which they could use for paying to improve their rangelands. The previous studies by Pender and Kerr (1998), Foti et al. (2007), and Nyongesa et al. (2016) indicated that farm income improves the capacity of farmers and positively influences their decisions to invest in agricultural interventions such as payment for ecosystem services.

Goat ownership was found to have significantly added an impetus to farmers' WTP. The likelihood of goat owners paying for rangeland improvements was greater than non-goat owners, which suggest that goats were exerting more pressure on the grazing resources through browsing, which necessitates improved conservation and replenishment investment by farmers. A study by O'Connor et al. (2011), found that increasing the proportion of sheep to cattle resulted in a decrease in the richness of the grassland used for grazing, demonstrating that increasing the number of animals might put pressure on grazing resources.

The finding that rangeland ecozone reduced farmers' WTP for rangeland regeneration and conservation could be attributed to the high quality of cattle fodder resources derived from sweet rangeland ecozones, which explains the low WTP of farmers. Sweet rangelands retain their palatability and high nutritive value throughout the year (Nqeno et al., 2011), and the quality of the forage never deteriorates to the point that animals cannot maintain growth (Ellery et al., 1995). However, sweet veld occurs in low rainfall areas, and fodder shortages are often expected in drought conditions and with high livestock densities, suggesting the need for strategies to reduce the risks, including paying for rangeland improvements. On the other hand, sour rangelands ecozones are characterized by a marked decline in forage quality during autumn and winter as grasses mature and senesce (Dedekind et al., 2020; Jordaan and de Ridder, 2017), causing seasonal forage bottlenecks, which can be highly problematic to farmers. This, therefore, confirms the finding that farmers on sour rangeland ecozones had high WTP for improving rangelands.

Due to the lack of previous investment in the protection of cattle grazing ecosystems and the high WTP estimates observed above, the current study suggests developing and implementing payment for ecosystem services strategies to improve cattle grazing rangelands in smallholder farming systems. The current study observed that farmers were somehow practising rangeland conservation and regeneration at their farms, suggesting the need for sustainable programmes to support such initiatives. The payment of user fees by farmers and government subsidies through shared public-private investment arrangements or government-farmer cost-sharing arrangements could, therefore, be viable financing options for improving the productivity and sustainability of rangelands (Doğan et al., 2020; Papagallo, 2018).

4.6 Conclusion

The study provides a case-study evaluation of farmers' WTP for improving rangelands and the underlying factors influencing their WTP decisions. The high WTP of commercially oriented beef farmers implies that rangeland ecosystems are essential inputs in their livestock farming systems, and they are willing to invest in improving their conditions. This could also entail the ability of farmers to pay for new technologies such as the LMDS. Invariably, higher education and long tenure enhances farmers' productivity efficiency and promotes a more positive attitude and understanding of the importance of conserving natural resources such as rangelands. Therefore, smallholder farmers should be exposed to various training programmes to improve their educational levels. The presence of goats in rangeland-based cattle farming systems can help maximize grazing resources but maintaining optimal stocking rates is recommended to prevent ecosystem degradation and the higher costs of maintaining them. The indigenous cattle genetic resources in Africa are primarily dependent on rangelands for feed, indicating that farmers should invest in the conservation of rangelands to ensure adequate feed supplies. The factors that affect farmers' WTP may have considerable spinoff benefits to policy decisions and should be accounted for when developing sustainable rangeland regeneration and conservation strategies with smallholder farmers. Therefore, payment for ecosystem services programmes could be designed and implemented by allowing farmers themselves to improve their rangelands, but this deserves further study to gain deeper insights. The LMDS can help in implementing such programmes that promote rangeland regeneration and conservation and encourage farmers to share rangeland management practices.

4.7 References

Aladi F and Olujobi J (2014) Farmers Perception of Opportunities Preferences and Obstacles of Growing Multipurpose Trees on Farmland in Kogi State. *European Scientific Journal* 1010(1414): 1857–7881. DOI: https://doi.org/10.19044/ESJ.2014.V10N14P%25P.

Asrat P, Belay K and Hamito D (2004) Determinants of farmers' willingness to pay for soil conservation practices in the southeastern highlands of Ethiopia. *Land Degradation and Development* 15(4): 423–438. DOI: 10.1002/ldr.623.

Bani BK and Damnyag L (2017) Farmers' Willingness to Pay for the Provision of Ecosystem Services to Enhance Agricultural Production in Sene East District, Ghana. *Small-scale Forestry* 16(4). Springer Netherlands: 451–467. DOI: 10.1007/s11842-017-9364-3.

Bester J, Matjuda LE, Rust JM, et al. (2003) The Nguni: A Case Study. In: *Community Management of Animal Genetic resources*, Mbabane, Swaziland, 2003, pp. 45–68. FAO.

Bikila NG, Tessema ZK and Abule EG (2016) Carbon sequestration potentials of semi-arid rangelands under traditional management practices in Borana, Southern Ethiopia. *Agriculture, Ecosystems and Environment* 223. Elsevier B.V.: 108–114. DOI: 10.1016/j.agee.2016.02.028.

Bishop RC and Heberlein TA (1979) Measuring Values of Extramarket Goods: Are Indirect Measures Biased? *American Journal of Agricultural Economics* 61(5): 926–930. DOI: 10.2307/3180348.

Blignaut J, Aronson J, Mander M, et al. (2008) Investing in natural capital and economic development: South Africa's Drakensberg Mountains. *Ecological Restoration* 26(2): 143–150. DOI: 10.3368/er.26.2.143.

Briske DD (2017) Rangeland Systems: Foundation for a Conceptual Framework. In: Briske DD (ed.) *Rangeland Systems: Processes, Management and Challenges*. Springer Open, pp. 1–24. DOI: 10.1007/978-3-319-46709-2_8.

Daemane ME, Cilliers SS and Bezuidenhout H (2010) An ecological study of the plant communities in the proposed Highveld National Park, in the peri-urban area of Potchefstroom, South Africa. *Koedoe* 52(1): 1–8. DOI: 10.4102/koedoe.v52i1.708.

DALRRD (2019) *Profile of the South African Beef Market Value Chain*. Department of Agriculture Land Reform and Rural Development (DALRRD), Pretoria, South Africa.

Danquah J and Kuwornu J (2015) Assessment of Farm Households' Willingness to Participate in Reforestation Projects in Ghana: Implications for Policy. *American Journal of Experimental Agriculture* 8(3): 186–192. DOI: 10.9734/ajea/2015/16348.

Dedekind LJ, McCosh J, Everson TM, et al. (2020) The value of rested sourveld in a communal grazing area in the Eastern Cape, South Africa. *African Journal of Range and Forage Science* 37(2): 191–195. DOI: 10.2989/10220119.2020.1744726.

Descheemaeker K, Oosting SJ, Homann-Kee Tui S, et al. (2016) Climate change adaptation and mitigation in smallholder crop–livestock systems in sub-Saharan Africa: a call for integrated impact assessments. *Regional Environmental Change* 16(8). Springer Berlin Heidelberg: 2331–2343. DOI: 10.1007/s10113-016-0957-8.

Desmet P, Schaller R and Skowno A (2009) *North West Province Biodiversity Conservation Assessment Technical Report*. Mafikeng. Available at: https://conservationcorridor.org/cpb/Desmet_et_al_2009_v2.pdf.

Doğan HP, Aydoğdu MH, Sevinç MR, et al. (2020) Farmers' willingness to pay for services to ensure sustainable agricultural income in the GAP-Harran plain, Şanlıurfa, Turkey. *Agriculture (Switzerland)* 10(5): 1–16. DOI: 10.3390/agriculture10050152.

du Pisanie K (2019) Mechanical methods for Karoo veld restoration. *Stackfarm* 9(6): 23–25. DOI: https://journals.co.za/doi/10.10520/EJC-161d1af7ff.

Dutilly-diane C, McCarthy N, Turkelboom F, et al. (2007) *Could payments for environmental services improve rangeland management in Central Asia, West Asia and North Africa? CGIAR Systemwide Program on Collective Action and Property Rights (CAPRi*. 62. Washington DC. DOI: 10.2499/capriwp62.

Ellery WN, Scholes RJ and Scholes MC (1995) The distribution of sweetveld and sourveld in south africa's grassland biome in relation to environmental factors. *African Journal of Range and Forage Science* 12(1): 38–45. DOI: 10.1080/10220119.1995.9647860.

FAO (2016) *AQUASTAT Country Profile: South Africa*. Food and Agriculture Organisation (FAO). Rome. DOI: 10.21552/cclr/2010/4/146.

Farley J (2012) Ecosystem services: The economics debate. *Ecosystem Services* 1(1). Elsevier: 40–49. DOI: 10.1016/j.ecoser.2012.07.002.

Fonta WM, Ayuk ET and van Huysen T (2018) Africa and the Green Climate Fund: current challenges and future opportunities. *Climate Policy* 18(9). Taylor and Francis: 1210–1225. DOI: 10.1080/14693062.2018.1459447.

Foti R, Nyakudya I, Moyo M, et al. (2007) Determinants of Farmer Demand for "Fee-for-Service" Extension in Zimbabwe: The Case of Mashonaland Central province. *Journal of International Agricultural and Extension Education* 14(1): 95–104. DOI: 10.5191/jiaee.2007.14108.

Garbach K, Lubell M and DeClerck FAJ (2012) Payment for Ecosystem Services: The roles of positive incentives and information sharing in stimulating adoption of silvopastoral conservation practices. *Agriculture, Ecosystems and Environment* 156. Elsevier B.V.: 27–36. DOI: 10.1016/j.agee.2012.04.017.

Gosbert LS, Athman KA and Jumanne MA (2019) Factors determining crop farmers willingness to pay for agricultural extension services in Tanzania: A case of Mpwapwa and Mvomero Districts. *Journal of Agricultural Extension and Rural Development* 11(12): 239–247. DOI: 10.5897/jaerd2019.1097.

Haab TC and McConnell K (2013) *Valuing Environmental and Natural Resources: The Econometrics of Non-Market Valuation* (WE Oates and H Folmereds). United Kingdom: Edward Elgar Publishing Limited. DOI: 10.4337/9781843765431.

Hanemann M, Loomis J and Kanninen B (1991) Statistical Efficiency of Double-Bounded Dichotomous Choice Contingent Valuation. *American Journal of Agricultural Economics* 73(4): 1255–1263. DOI: 10.2307/1242453.

Herrero M, Havlík P, Valin H, et al. (2013) Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences of the United States of America* 110(52): 20888–20893. DOI: 10.1073/pnas.1308149110.

ITU (2020) *Measuring digital development: Facts and figures 2020. ITU Publications*. International Telecommunication Union (ITU), Geneva. Available at: https://www.itu.int/en/mediacentre/Documents/MediaRelations/ITU Facts and Figures 2019 - Embargoed 5 November 1200 CET.pdf.

Jordaan G and de Ridder N (2017) Overwintering on sourveld in the Eastern Cape: feeds and grazing. *Sabinet African Journals* 7(11): 26–29. DOI: https://hdl.handle.net/10520/EJC-bffe89fdb.

Kidane TT, Wei S and Sibhatu KT (2019) Smallholder farmers' willingness to pay for irrigation water: Insights from Eritrea. *Agricultural Water Management* 222(May). Elsevier: 30–37. DOI: 10.1016/j.agwat.2019.05.043.

Kioko J, Kiringe JW and Seno SO (2012) Impacts of livestock grazing on a savanna grassland in Kenya. *Journal of Arid Land* 4(1): 29–35. DOI: 10.3724/SP.J.1227.2012.00029.

Kotze I and Rose M (2015) *Farming Facts and Futures: Reconnecting South Africa's Food Systems to its Ecosystems*. Cape Town. Available at: https://www.wwf.org.za/food/?13821/farming-facts.

Lalika MCS, Meire P, Ngaga YM, et al. (2017) Willingness to pay for watershed conservation: are we applying the right paradigm? *Ecohydrology and Hydrobiology* 17(1). European Regional Centre for Ecohydrology of the Polish Academy of Sciences: 33–45. DOI: 10.1016/j.ecohyd.2016.12.004.

Le Maitre DC, O'Farrell PJ, Milton SJ, et al. (2009) *Assessment and evaluation of ecosystem services in the Succulent Karoo biome*. *South African National Biodiversity Institute*. Cape Town.

Lebacq T, Baret P V. and Stilmant D (2013) Sustainability indicators for livestock farming. A review. *Agronomy for Sustainable Development* 33(2): 311–327. DOI: 10.1007/s13593-012-0121-x.

Leroy G, Hoffmann I, From T, et al. (2018) Perception of livestock ecosystem services in grazing areas. *Animal* 12(12). Elsevier: 2627–2638. DOI: 10.1017/S1751731118001027.

Letsoalo NL (2019) *Rangeland management practices among emerging livestock farmers in Gauteng province , South Africa*. University of South Africa. Available at: https://uir.unisa.ac.za/handle/10500/25597.

Lopez-Feldman A (2012) Introduction to contingent valuation using Stata. *MPRA Paper* (41018): 16. Available at: http://mpra.ub.uni-muenchen.de/41018/.

Malusi N, Falowo AB and Idamokoro EM (2021) Herd dynamics, production and marketing constraints in the commercialization of cattle across Nguni Cattle Project beneficiaries in Eastern Cape, South Africa. *Pastoralism* 11(1). Pastoralism: 1–12. DOI: 10.1186/s13570-020-00186-x.

Mapiye C, Chikwanha OC, Chimonyo M, et al. (2019) Strategies for sustainable use of indigenous cattle genetic resources in Southern Africa. *Diversity* 11(11): 1–14. DOI: 10.3390/d11110214.

Mapiye O, Makombe G, Mapiye C, et al. (2018) Limitations and prospects of improving beef cattle production in the smallholder sector: a case of Limpopo Province, South Africa. *Tropical Animal Health and Production* 50(7). Springer Netherlands: 1711–1725. DOI: 10.1007/s11250-018-1632-5.

Meissner H, Scholtz M and Palmer A (2014) Sustainability of the South African Livestock Sector towards 2050 Part 1: Worth and impact of the sector. *South African Journal of Animal Science* 43(3): 282. DOI: 10.4314/sajas.v43i3.5.

Mukama PC (2010) *Economic benefit and Willingness to pay for improved Rangelands in Uganda*. Makerere University.

Ning J, Jin J, Kuang F, et al. (2019) The Valuation of Grassland Ecosystem Services in Inner Mongolia of China and Its Spatial Differences. *Sustainability (Switzerland)* 11(24): 1–14. DOI: 10.3390/su11247117.

Nqeno N, Chimonyo M and Mapiye C (2011) Farmers' perceptions of the causes of low reproductive performance in cows kept under low-input communal production systems in South Africa. *Tropical Animal Health and Production* 43(2): 315–321. DOI: 10.1007/s11250-010-9691-2.

Nyongesa JM, Bett HK, Lagat JK, et al. (2016) Estimating farmers' stated willingness to accept pay for ecosystem services: case of Lake Naivasha watershed Payment for Ecosystem Services scheme-Kenya. *Ecological Processes* 5(1). Ecological Processes: 1–15. DOI: 10.1186/s13717-016-0059-z.

O'Connor TG, Martindale G, Morris CD, et al. (2011) Influence of grazing management on plant diversity of Highland Sourveld grassland, Kwazulu-Natal, South Africa. *Rangeland Ecology and Management* 64(2). Elsevier: 196–207. DOI: 10.2111/REM-D-10-00062.1.

Oldekop JA, Rasmussen LV, Agrawal A, et al. (2020) Forest-linked livelihoods in a globalized world. *Nature Plants* 6(12). Springer US: 1400–1407. DOI: 10.1038/s41477-020-00814-9.

Ouédraogo M, Barry S, Zougmoré RB, et al. (2018) Farmers' willingness to pay for climate information services: Evidence from Cowpea and Sesame producers in Northern Burkina Faso. *Sustainability (Switzerland)* 10(3). DOI: 10.3390/su10030611.

Palmer AR and Bennett JE (2013) Degradation of communal rangelands in South Africa: towards an improved understanding to inform policy. *African Journal of Range and Forage Science* 30(1–2): 57–63. DOI: 10.2989/10220119.2013.779596.

Papagallo L (2018) *Operationalizing payments for ecosystem services for pastoralists in rangeland settings*. Montpellier. Available at: https://cgspace.cgiar.org/handle/10568/92345.

Pender JL and Kerr JM (1998) Determinants of farmers' indigenous soil and water conservation investments in semi-arid India. *Agricultural Economics* 19(1–2): 113–125. DOI: 10.1111/j.1574-0862.1998.tb00520.x.

Sambo JM (2020) *Evaluation of the Nguni cattle reproductive perfomance in the Communal Property Associations and privately owned enterprises across the different ecological zones of Mpumalanga Province*. University of Limpopo.

SAS Institute (2012) SAS/STAT User's Guide. 9.3. New York city.

Shee A, Azzarri C and Haile B (2020) Farmers'willingness to pay for improved agricultural technologies:

Evidence from a field experiment in Tanzania. *Sustainability (Switzerland)* 12(1). DOI: 10.3390/SU12010216.

Sherbut G (2012) *Payment for ecosystem services in South Africa : Prospects for programme development*. Pretoria, South Africa.

Sooriyakumar K, Sivashankar S and Sireeranhan A (2019) Farmers' willingness to pay for the ecosystem services of organic farming: A locality study in Valikamam area of Sri Lanka. *Applied Ecology and Environmental Research* 17(6): 13803–13815. DOI: 10.15666/aeer/1706_1380313815.

StataCorp (2019) Stata Statistical Software.

Taha EA and Khidr RE (2011) Rangeland management and animal production sustainability under arid and semi arid conditions: Egypt overview. In: Bernués A, Boutonnet JP, Casasus M, et al. (eds) *Economic, Social and Environmental Sustainability in Sheep and Goat Production Systems.* Zaragoza, pp. 317–322. Available at: http://om.ciheam.org/om/pdf/a100/00801522.pdf.

Tsan M, Totapally S, Hailu M, et al. (2019) *The Digitalisation of African Agriculture: Report 218-219*. Wageningen.

Uddin E, Gao Q and Mamun-Ur-Rashid MD (2016) Crop Farmers' Willingness to Pay for Agricultural Extension Services in Bangladesh: Cases of Selected Villages in Two Important Agro-ecological Zones. *Journal of Agricultural Education and Extension* 22(1). Taylor and Francis: 43–60. DOI: 10.1080/1389224X.2014.971826.

Upton C, Dorligsuren D, Dulmaa D, et al. (2015) *Pastures, Conservation and Climate Action, Mongolia: Plan Vivo Project Design Document*. *Plan Vivo Project Design Document*. Available at: http://www.planvivo.org/docs/Pastures-Conservation-and-Climate-Action-Mongolia-PDD-2016.pdf%0Ahttp://dx.doi.org/10.1016/j.wace.2014.12.001%0Ahttp://dx.doi.org/10.1016/j.wace.2015.05.002%0Awww.uniquindio.edu.co%0Ahttp://www.fao.org/3/a-i5695e.pdf%0Ahttp://.

Vercueil J (2000) *Introduction and General Description of the Method of Contingent Valuation*. Rome.

Wisely SM, Alexander K, Mahlaba T, et al. (2018) Linking ecosystem services to livelihoods in southern Africa. *Ecosystem Services* 30(March). The Authors: 339–341. DOI: 10.1016/j.ecoser.2018.03.008.

Wooldridge JM (2012) *Introductory Econometrics: A Modern Approach*. 6th ed. Cincinnati, USA: South-Western College Publishing.

Xiong K, Kong F, Zhang N, et al. (2018) Analysis of the factors influencing willingness to pay and payout level for ecological environment improvement of the Ganjiang River Basin. *Sustainability (Switzerland)* 10(7). DOI: 10.3390/su10072149.

Yahdjian L, Sala OE and Havstad KM (2015) Rangeland ecosystem services: Shifting focus from supply to reconciling supply and demand. *Frontiers in Ecology and the Environment* 13(1): 44–51. DOI: 10.1890/140156.

Zaiton S, M, Huda-Fahana M and Hasan-Basri B (2019) Conservation of Mangroves in Kuala Perlis, Malaysia-A Case Study of Socio-Economic Atributes of Fisherman Driving Valuation in Sustaianing Livelihoods Through Forest Management. *Journal of Tropical Forest Science* 31(4): 433–442. DOI: http://dx.doi.org/10.26525/jtfs2019.31.4.433.

Chapter 5: Perceptions of the usefulness of LMDS in livestock production amongst commercially oriented smallholder cattle producers

Abstract

One of the complex challenges of driving the growth of commercially oriented smallholder farmers is ensuring that farmers understand and use new technologies. Thus, explaining users' behavioural intentions before technology development is one of the most effective ways to increase adoption and identify potential design issues. The study investigated the perceived usefulness of a proposed LMDS in livestock production by the farmers. All hundred and one beef cattle producers actively participating in the Industrial Development Corporation (IDC)-Nguni cattle programme in North West province were interviewed using a structured questionnaire to collect data. Four Focus Group Discussions and six Key Informant Interviews were conducted with farmers and agricultural extension officers, respectively. Quantitative data were analysed using descriptive statistics, and the chi-square statistic was computed to determine the relationship between farmer's socio-economic characteristics and their perceptions of the proposed LMDS. Qualitative data were analysed using thematic analysis. Results revealed that over 75% of the farmers had smartphones and smartphone operating skills, and nearly two-thirds were using the internet to search for agricultural information. About 80% had a strong positive perception of the usefulness of the proposed LMDS towards their livestock production. FGDS and KIIs, also observed higher positive perceptions towards the innovation. The Chi-square statistic results show that education level, smartphone ownership, farming experience, cattle herd size and gender influenced farmers' perceptions of the LMDS. Poor mobile network connectivity (44%) and lack of digital skills (20%) were the limitations perceived to hamper the usefulness of the innovation. The factors that influenced farmers' perceptions and the identified possible limitations to adoption should be accounted for to ensure the adoption and scaling of new technologies. The deeper insights from study findings on the perceived usefulness of mobile technology can be beneficial to policymakers, researchers, and development agents and institutions when developing interventions for adoption by farmers.

5.1 Introduction

Agriculture is one of the vital sectors where ICTs, particularly mobile technologies, are gradually being diffused to improve smallholder farmers' productivity and welfare development (Emeana et al., 2020; Khan et al., 2019; Smidt, 2021). However, one of the complex challenges of introducing new technologies to farmers in developing and emerging economies is ensuring adoption and implementation (Agholor and Ogujiuba, 2021; Jha et al., 2020; Mwangi and Kariuki, 2015). Numerous factors may explain this, including poor infrastructure, weak institutions and unfavourable policies, lack of access to information and technical skills (FAO, 2009; Mwangi and Kariuki, 2015), low education (Misaki et al., 2018) and resource constraints (Khan et al., 2019). A lack of understanding of users' behavioural intentions before technology development and deployment can create huge obstacles to adoption and can lead to failure to identify potential design issues (Mwangi and Kariuki, 2015; Taherdoost, 2018).

Invariably, there are indications that ICT-based interventions facilitate access to valuable agricultural information, inputs and services in commercially oriented smallholder farming systems where skills and resources are scarce (Aker, 2011; Khan et al., 2019). The technologies are perceived to reduce the information asymmetry that prevents smallholder farmers from accessing modern technologies for enhancing production (Ogutu et al., 2014). For instance, the technologies can present opportunities where farmers could share innovations and skills which can be used to drive change and sustainably grow farming systems (Daum et al., 2018; FAO, 2017). A further advantage of using ICT-based technologies, particularly mobile phones and the internet, is that farmers can directly provide feedback to agricultural extension systems (Baruah and Mohan, 2018; Ogutu et al., 2014) and receive tailored solutions in real-time. As a result, mobile technologies using the internet are perceived to help broaden the orientation of farmers in sustainable production activities, thereby driving a significant turnaround in the agricultural sector (Batchelor et al., 2014; Bizikova et al., 2020).

There are numerous examples of mobile-based technologies developed and deployed to support the transformation of subsistence smallholder farmers and improve the delivery of agricultural extension services in developing countries (Aker, 2011; Kassem et al., 2021; Khan et al., 2019). This conforms to a recent observation by Agholor and Ogujiuba (2021), where some farmers at the commercial level consented in general that ICTs helped in improving their production performance. However, research continues to show that ICT-based agricultural technologies are being slowly adopted, especially among marginalised and resource-poor farmers in developing and emerging economies (Edwards et al., 2014; Sekabira et al., 2012; Smidt, 2021). Therefore, unwillingness to adopt the technologies has been characterised as one of the primary factors stagnating the growth of smallholder farming (Aker, 2011) and its transformation to commercial agriculture. Due to the persistence and importance of this problem, understanding and gaining insights into farmers' technology adoption behaviour has been a long-standing issue in research.

Invariably, the research shows that the involvement of farmers (end users) in the development process of ICT-enabled agricultural initiatives is limited, despite expectations that farmers should adopt the interventions (Henze and Ulrichs, 2016; Misaki et al., 2018; Tsan et al., 2019). Thus, Emeana et al. (2020) argued that the currently developed dozens of digital interventions for farmers are being brought in rapid succession and have limitations in their ability to scale and effectively transform smallholder farming because they are not user driven. Nonetheless, Massresha et al. (2021) note that it is critical to understand that decisions by farmers to adopt new agricultural innovations is not an overnight phenomenon and is dependent on various complex factors. Conventionally, the most studied factors considered to guide technology adoption by farmers are their socioeconomic and farm characteristics, institutional factors, and access to resources (Adesina and Baidu-Forson, 1995; Baruah and Mohan, 2018; Feder and Umali, 1993; Sekabira et al., 2012). Some empirical studies reveal that in addition to these factors, farmers' subjective preferences of the innovation-specific characteristics (Adesina and Baidu-Forson, 1995) and their knowledge, attitudes and perceptions (Alomia-Hinojosa et al., 2018; Massresha et al., 2021; Meijer et al., 2015) are important in influencing their adoption behaviour towards technologies. For instance, Gagnon et al. (2012) shows that targeted user perception of the benefits of the innovation (system usefulness) was the most common facilitating factor towards technology adoption. Thus, end-users tend to adopt or not adopt an innovation based on the perceived usefulness or the extent they believe it will assist them to perform their job activities better (Davis, 1989; Massresha et al., 2021).

Perceived usefulness is defined by Davis (1989) as "the degree to which a person believes that using a particular system would enhance his or her job performance." Further to that, Choudhary and Suri (2013) note that participatory approaches are a means to enhance perceived usefulness and the diffusion of agricultural innovations amongst end-users which might drive adoption. Therefore, participatory actions can be a wider comprehension of adoption, especially with the direct involvement of developers and end-users in the beginning stage of the technology development process (Alomia-Hinojosa et al., 2018; Taherdoost, 2018). Although several studies have been conducted on farmer perceptions of agricultural technologies in developing countries (Aldosari et al., 2019; Deressa et al., 2009; Kitinya et al., 2012; Massresha et al., 2021; Osondu and Ibezim, 2015), assessment of the perceived usefulness of technologies prior to use is underexplored. Thus, assessing the levels of farmers' objective and subjective attitudes and perceptions before using technologies is critical as it can lead to the creation of user-friendly and sustainable interventions that the farmers can adopt (Ingram and Gaskell, 2019; Taherdoost, 2018). Therefore, the primary objective of this study was to empirically assess the perceptions of commercially oriented smallholder farmers on the usefulness of the LMDS being developed to upscale their livestock production.

5.2 Methodology

5.2.1 Research design

The study was guided by a pragmatic paradigm that accommodates positivists (quantitative) and social constructivists (qualitative) perspectives (Creswell, 2014). A partially mixed sequential design with the quantitative method being dominant was adopted. Quantitative data was collected first (using surveys), followed by qualitative data collection using FGDs and KIIs. The FGDs and KIIs were used to probe and validate data gathered from the surveys (Bryman, 2003)

5.2.2 Participant selection, sample sizes and study site description

The study was conducted in the North-West Province of South Africa with commercially oriented cattle producers who are beneficiaries of the North-West IDC-Nguni cattle programme and with agricultural extension officers. The sample constituted all 101 farmers actively participating in the programme. Description of the study site and selection of respondents were discussed in chapter 4 (Table 4.1; Figure 4.1). FGDs samples were purposively selected from the survey sample (used in the quantitative phase) with assistance from extension officers. Four FGDs were conducted with sample sizes between 5 and 7 respondents. Generally, the size of FGDs is recommended to be between 10 and 12 (Creswell, 2014; Neuman, 2007). However, given that the sample size for the study was 101, the size of the FGD was made to be just above half the recommended size to reduce the proportion of the total sample participating in the FGDs. Six agricultural extension advisors specialising in livestock production were selected from the province's four districts to participate in the KIIs.

5.2.3 Quantitative data collection

A structured questionnaire was used for data collection (Appendix 1). The data collection procedure is described in chapters 4 and 5. Data on farmers' perceptions of the usefulness of the LMDS and perceived limitations to its adoption were gathered. Eighteen prescribed statements were used to identify respondents' perceptions against a 5-point Likert scale as follows: Strongly agree = 5; Agree = 4; Undecided = 3; Disagree = 2 and Strongly disagree = 1 (Joshi et al., 2015). The study also collected data on mobile phone ownership, network connectivity, internet use, and experiences with mobile app.

5.2.4 Qualitative data collection

Given the interest to understand the perceptions of farmers on the usefulness of the LMDS towards livestock production, FGDs and KIIs were conducted to validate findings from the quantitative study. The study involved four FGDs conducted at the DALRRD's district centres and lasting about an hour. The discussions began with an understanding of the farmers' experiences with the current extension systems; in terms of who is giving them services, service delivery channels being used, and challenges they face in accessing the services. Data on farmers' experiences with ICTs, respondents' perceptions on the usefulness of the proposed LMDS technology, WTP and possible challenges to its adoption were also collected. An interview guide (Appendix 2) was developed to facilitate the discussions and ensure that the discussions' in-depth views and opinions are explored. It helped keep the meeting on track while permitting respondents to discuss freely and naturally the topics covered (Creswell, 2014). An FGD facilitator was hired to moderate the discussions in the Setswana language and the Department of Agriculture (district offices) organised the meeting venues. During the meeting, an assistant took notes to capture the main points highlighted by the discussants and important non-verbal cues were also noted. Given that data collection was conducted during the COVID-19 pandemic outbreak, all COVID-19 protocols were observed. FGDs were recorded using the high-quality recorder and later transcribed verbatim.

Six KIIs with agricultural extension advisors involved in cattle production were conducted to capture in-depth information and insights about agricultural extension delivery, experiences with ICTs, perceptions of the LMDS and the performance of the Nguni cattle programme farmers in the province. Since the key informants were all from the same agricultural discipline and province, the adopted sample size was sufficient to ensure data saturation, as significant amounts of repetition and overlapping of responses were observed during interviews. All interviews were conducted in English and through face-to-face by use of a semi-structured interview guide to capture data (Appendix 3). The FGD data were used to validate the quantitative data and the KII data were used to validate the FGD data. Given that data collection was conducted during the COVID-19 pandemic outbreak, all COVID-19 protocols were observed. A high-quality audio recorder was used to record the KII interviews which were later transcribed verbatim by the researcher.

5.2.5 Quantitative data Analysis

The quantitative data were analysed using the Statistical Analytical System (SAS Institute, 2012). Descriptive statistics (frequency counts, percentages, and cross-tabulations) were used to analyse all quantitative data using the PROC FREQ procedure of SAS. The Chi-square ($\chi 2$) was used to test for association between farmer characteristics and perceptions of the usefulness of the proposed LMDS in improving livestock production. $\chi 2$ is a non-parametric test for measuring how far the observed counts are from the expected counts (Moore et al., 2013). The test is 2-sided (non-directional) and was conducted at a 95% confidence level ($p<0.05$). Unlike most statistics, chi-square provides information about the significance of observed differences and the categories explaining the differences (Mchugh, 2013). The formula for the statistic is expressed as:

$$x^2 = \sum \frac{(\textbf{observed count} - \textbf{expected count})^2}{\textbf{expected count}}$$

Source: Moore et al. (1999)

For this chi-square test, the dependent variable (ordinal) were farmer perception levels on the 5-point Likert scale and the independent variables (dichotomous) were educational level (1= above grade 10; 0= otherwise), smart phone ownership (1= own smartphone; 0= no smartphone), gender (1= female; 0= otherwise), farming experience (1= experienced (above mean=19 years); 0= not experienced), and cattle herd size (1= large herd (above mean=103); 0= small herd).

5.2.6 Qualitative data analysis

The analysis of all qualitative data was undertaken by following a framework of the thematic analysis described in Chapter 3. A multistage approach was adopted and followed some of the phases outlined by Braun and Clarke (2006). Table 5.1 presents the main phases conducted in this study. An inductive (theory-driven) thematic analysis involving the use of the specific research question(s) in the interview guides (Neuman, 2007) and the analyst's focus was employed.

Table 5. 1 The phases of Thematic Analysis involved

Phase	Description
1. Familiarising with data sets	Audio files were translated and transcribed into word documents. This was followed by reading and re-reading of the transcripts and observation of meanings and patterns that appears across the data sets.
2. Generating Initial Codes	The concern was to address specific research questions (theoretical thematic analysis). Each segment of data that seemed relevant or captured something relevant to the research questions was coded. The Atlas-ti V8 software was used to carry out the exercise.
3. Searching and Reviewing themes	Codes were collated into potential themes which align to the areas of the study. Atlas ti was used to group all excerpts associated with a particular code.
4. Defining and Naming themes	Ensuring that each theme has enough data to support them and is distinct. Generating clear definitions and names for each theme based on the available study categories. Formulating how the themes could come together into a narrative.
5. Reporting findings	Interpretive analysis and making arguments from the findings to support and validate findings from the quantitative study.

5.3 Quantitative results

5.3.1 Distribution of Farmers based on awareness, use, and experiences of mobile and internet-based technologies.

The study results indicate that all respondents had mobile phones, 75% being smartphones. Over 80% of those who owned smartphones had at least secondary education and were married. Thirty five percent of respondents owned personal computers (laptops). Eighty-four per cent expressed that they had skills to operate smartphones by themselves, with 50% having high to very high skills (Figure 5.1). Almost all the farmers who reported low skills had another household member with good smartphone operating skills.

About 64% indicated very good access to network connectivity, and the average monthly mobile phone subscription was ZAR740. Ninety percent of the farmers indicated that they rely on government extension for agricultural information and services and nearly two-thirds also searched for agricultural information on the internet. Those who searched for information on the internet searched for information about general farm management (23%), animal health (34%), cattle breeds and breeding management (19%), cattle markets and marketing (20%), and cattle feed and feed management (6%). Over 80% of respondents reported that they were aware of some ICT-based applications and the common ones were Facebook (77%), WhatsApp (93%), Twitter (27%), and others such as Instagram (7%), Voermol (4%), Gmail app (4%), and mobile banking Apps (3%) and YouTube (2%). More than three-quarters of the respondents used the identified mobile and internet-based Apps to support their farming businesses. Facebook was mainly used for sharing information through agricultural groups (42%), searching general livestock farming information (25%) and accessing markets and marketing information (21%). WhatsApp was largely used for communicating with other farmers (93%), agricultural extension personnel (65%) and with industry services providers (2%). For those who were not using the Apps (18%), the main reasons were lack of skills (42%), not being aware of any Apps (24%) and no access to smartphones (24%).

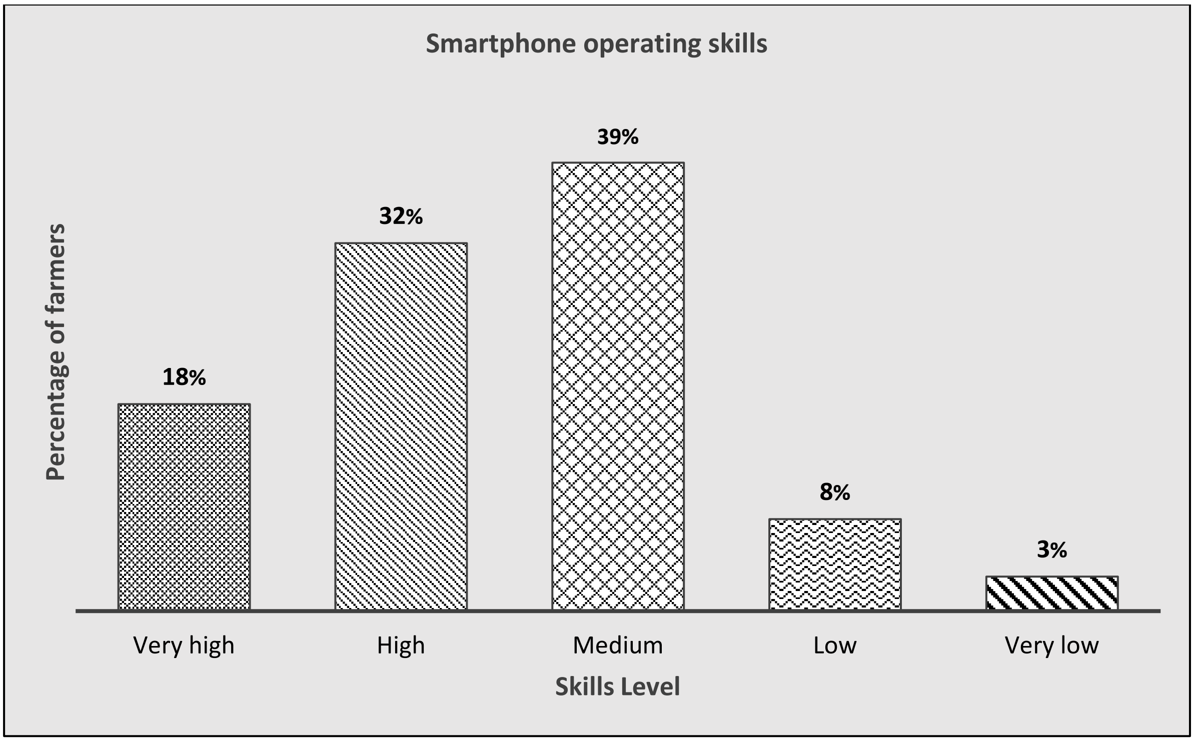

Figure 5. 1 Commercially oriented cattle farmers' skills in operating smartphones

5.3.2 Farmers' perceptions of the usefulness of the LMDS

The study results showing the farmers' perceptions regarding the usefulness of the proposed LMDS are presented in Table 5.2. Of the 18 prescribed positive statements regarding the usefulness of the proposed LMDS in improving access to extension services and livestock production, findings show that most respondents (over 90%) had highly positive perceptions towards the innovation as shown in table 5.2. Table 5.2 shows that on average 83% agreed with statements which had positive attributes of the LMDS with 13% percent t strongly agreeing. About 80% of the respondents strongly agreed with the statement that the proposed LMDS would help them acquire information on livestock production, while 13% agreed, 6% were unsure, and only 1% disagreed with the statement. Table 5.2 also shows that over 80% of respondents agreed that the system would promote skills sharing and collective activities among them. The same proportion also indicated that it would promote linkage between extension officers, researchers, and agricultural services providers. In order to validate the positive perceptions of the LMDS, three prescribed statements indicating probable limitations of the LMDS (stated in the negative) were included in the study. In order to validate the perceptions observed in the positive statements, the high score for the negative statements should be opposite of the positive statements. Table 5.2 shows that on average 77 percent disagreed with the negative statement with 51 percent strongly disagreeing. This is the reverse of the positive statements, thus validating the positive perceptions.

Table 5. 2 Distribution of farmers according to their perceptions of the usefulness of the proposed LMDS (%)

Perception Statement	SA	A	UD	D	SD
1. It helps in acquiring appropriate livestock production information	80	13	6	1	0
2. It is easier and quicker to access extension services	78	20	1	1	0
3. I will allow me to interact directly with extension officers	74	20	5	1	
4. Time and costs incurred in acquiring information will be saved	88	11	1	0	0
5. The system will allow me to interact with local researchers	79	17	2	2	0
6. It will ensure good access to market information in real-time	80	16	4	0	0
7. It will create opportunities for accessing better markets	83	15	2	0	0
8. It will improve the skills sharing between other farmers and me	88	9	1	1	1
9. It will enable me to collaborate with other farmers	85	14	1	0	0
10. The LMDS is a helpful tool for remotely located farmers	83	6	6	1	1
11. It can provide weather forecasts and danger alert in real-time	79	13	6	1	1
12. This is a good system for linking with agricultural service providers	89	9	2	0	0
13. It is suitable for record-keeping	86	10	4	0	0
14. It will enable farmers to report stock theft and locate stray animals	85	11	3	0	1
15. It will be helpful during periods like the COVID-19 pandemic	84	13	2	1	0
Mean	**83**	**13**	**3**	**1**	**0.3**
16. I will be challenging to use the LMDS because I lack technical skills	10	12	10	25	43
17. I will not be able to access the system because smartphones are costly	8	7	5	24	56
18. I will not be able to use it because mobile data is expensive	2	12	4	29	54
Mean	**7**	**10**	**6**	**26**	**51**

SD = Strongly Disagree; D = Disagree; UD = Undecided; A = Agree; SA = Strongly Agree; % = Percentage

5.3.3 Factors influencing farmers' perceptions of ICTs.

Table 5.3 presents the chi-square statistic results of the relationship between farmers' socioeconomic characteristics and their perceptions of the usefulness of the proposed LMDS. The computed reliability testing analytical results showed that the scale had good reliability (Cronbach's α=0.7544). In this instance, the results show that some of the farmers' responses to the statements were significantly ($p<0.05$) a function of education level, smartphone ownership, cattle herd sizes, gender and their livestock farming experience. For example, respondents' education was significantly associated with responses to statements such as the LMDS helps in acquiring appropriate livestock production information ($p = 0.01$), reduces costs and time incurred in acquiring information ($p = 0.01$) and that farmers might fail to use it due to lack of technical skills ($p = 0.03$). According to study results, having smartphones significantly influenced how farmers perceived the LMDS, such as it improves interaction with local researchers ($p = 0.02$), facilitates access to better markets ($p = 0.04$), and could be helpful during periods like the COVID-19 pandemic ($p = 0.03$). According to study results, having smartphones was positively associated with how farmers perceived the LMDS, such as it improves interaction with local researchers, facilitates access to better markets, and could be helpful during periods like the COVID-19 pandemic. The farmer responses on perception statements can also be used to assess the reliability of the results. For instance, for the two statements "The LMDS is a helpful tool for remotely located farmers" and "It is suitable for record-keeping" theory would guide that education would play a more significant role in the latter than the former, which is exactly the case with the results. If education had been significant in the former but not in the latter, then this would signify a possibility of unreliability.

Table 5. 3 The relationship between farmers' socioeconomic characteristics and their perceptions of the usefulness of the proposed LMDS

Perception Statement	Education	Owning smartphone	Cattle herd size	Gender	Experience
	p-value	p-value	p-value	p-value	p-value
It helps in acquiring appropriate livestock production information	0.003***	0.075 NS	0.048**	0.050**	0.718 NS
It is easier and quicker to access extension services	0.082 NS	0.207 NS	0.087 NS	0.001***	0.299 NS
I will allow me to interact directly with extension officers	0.085 NS	0.226 NS	0.093 NS	0.650 NS	0.018**
Time and costs incurred in acquiring information will be saved	0.008***	0.060 NS	0.144 NS	0.186 NS	0.016**
The system will allow me to interact with local researchers	0.049**	0.001***	0.015**	0.112 NS	0.455 NS
It will ensure good access to market information in real-time	0.425 NS	0.001***	0.127 NS	0.013**	0.144 NS
It will create opportunities for accessing better markets	0.050**	0.037**	0.004***	0.630 NS	0.069 NS
It will improve the skills sharing between other farmers and me	0.217 NS	0.222 NS	0.193 NS	0.358 NS	0.075 NS
It will enable me to collaborate with other farmers	0.001***	0.026**	0.019**	0.778 NS	0.015**
The LMDS is a helpful tool for remotely located farmers	0.079 NS	0.018**	0.017**	0.837 NS	0040**
It can provide weather forecasts and danger alert in real-time	0.323 NS	0.008***	0.099 NS	0.420 NS	0.354 NS
This is a good system for linking with agricultural service providers	0.076 NS	0.049**	0.000***	0.010***	0.252 NS
It is suitable for record-keeping	0.011**	0.016**	0.048**	0.384 NS	0.185 NS
It will enable farmers to report stock theft and locate stray animals	0.121 NS	0.562 NS	0.274 NS	0.002***	0.034**
It will be helpful during periods like the COVID-19 pandemic	0.028**	0.027**	0.410 NS	0.201 NS	0.063 NS
I will be challenging to use the LMDS because I lack technical skills	0.027**	0.426 NS	0.627 NS	0.012**	0.516 NS
I will not be able to access the system because smartphones are costly	0.013**	0.178 NS	0.677 NS	0.876 NS	0.473 NS
I will not be able to use it because mobile data is expensive	0.030**	0.456 NS	0.944 NS	0.412 NS	0.690 NS

Note: ***, **, * Statistical significance at 1% ($p<0.01$), 5% ($p<0.05$), 10% ($p<0.10$), respectively

5.3.4 The farmers' WTP for the LMDS

The study also assessed the respondents' WTP attitudes toward the LMDS, and Table 5.4 presents the results. Asked whether they would be willing to pay a full subscription fee, 84% of the farmers said they would be willing to pay, while 5% and 11% said they were unwilling or unsure (Table 5.4). Half of those unwilling to pay or not sure agreed to pay if the government paid 50% of the subscription fee. Overall, all farmers agreed to adopt the LMDS technology (Table 5.4). Despite the high WTP, farmers identified some of the limitations of LMDS adoption.

Table 5. 4 Farmers' WTP subscription fee for using the LMDS platform

Responses	WTP full subscription fee	WTP if Government pays 50%	Accepting the initiative if Government pays full subscription fee
Yes	84%	50%	100%
No	5%	33%	0
Not sure	11%	17%	0

These results are consistent with WTP assessments for for rangeland ecosystem services. From these two results it is clear that if farmers perceive a benefit, they their willingness to pay is positive. Thus, it can be reasonably assumed that *ceteris paribus*, as long farmers perceive the LMDS as beneficial, their WTP for subscribing to it will be positive.

5.3.5 Perceived constraints to the adoption and use of LMDS

Figure 5.2 presents the proportions of farmers who perceived constraints to the use of mobile-based technology. About 44% of respondents reported poor availability of network connectivity, while 20% perceived lack of digital skills as constraints to the adoption and use of LMDS technology. A small proportion of respondents (6%) indicated lack of access to smartphones and other digital tools, whereas 12 and 14% indicated high costs of internet and mobile data and limited access to administrative support, respectively, as challenges to adopting LMDS.

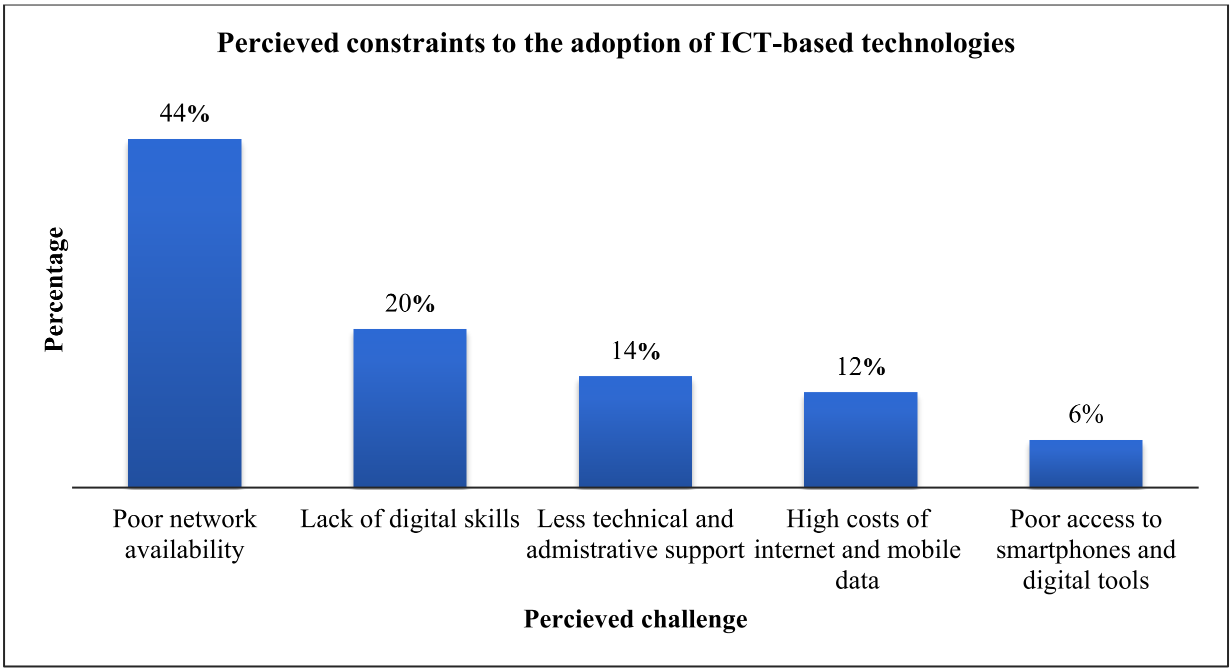

Figure 5. 2 The perceived constraints to the adoption of the LMDS by the farmers

5.3.6 Discussion of quantitative results

The finding that all farmers owned mobile phones, with most of them having smartphones, is supported by many previous studies (Kabir, 2015; Kassem et al., 2021; Masuka et al., 2016; Shemfe, 2018). Masuka et al. (2016) observed that 94% of smallholder farmers in Svosve-Wenimbi under Marondera district, Zimbabwe had mobile phones even under the harsh economic conditions existing in the country (Maunganidze et al., 2021). Elsewhere in Africa, Osondu and Ibezim (2015) reported that mobile phones were the most accessible and widely used digital tool by farmers in Imo State, Nigeria. These findings suggest that mobile and internet penetration is expanding in smallholder farming systems. The observed high smartphone adoption could be because smartphone handsets are becoming more affordable and readily available in local markets (Wyrzykowski, 2020). This could also be attributed to the fact that smartphones now offer users various functionalities, including taking photographs, audio recordings, and video recordings, as well as access to more authentic sources of information, such as agricultural Apps (Dehnen-Schmutz et al., 2016). Thus, large amounts of agricultural information and services available on websites, e-magazines, internet portals, social media platforms, and Apps are accessible through internet-connected smartphones (Dehnen-Schmutz et al., 2016; Khan et al., 2019).

The finding that low-skilled farmers had a household member with good smartphone operating skills implies that those household members could help them learn about new mobile technologies. Despite the increasing use of mobile phones and the internet to access agricultural information, the current study conforms to many previous studies indicating that government extension remains an important source of information and services for the smallholder farmers (Eicher, 2007; Mapiye et al., 2019; Raidimi and Kabiti, 2019). In South Africa, the DALRRD, through its provincial departments, has a *de facto* monopoly over the provision of extension and advisory services (Akpalu, 2013; DALRRD, 2014; Koch and Terblanché, 2013). This implies that innovations aiming to improve access to information and services should not be introduced as parallel systems but rather as an adjunct measure to the existing extension models. The aim is to take advantage of the existing working relationships between smallholders and government extension systems to ensure the farmers trust the technology.

The current finding that most respondents agree with statements suggesting a positive impact of the proposed LMDS platform is supported by the findings of Shemfe (2018) and Kivunike et al. (2011). According to the studies, ICTs were perceived as valuable tools for driving smallholder farming and quality of life change in rural farming communities. However, these results are not consistent with Aldosari et al. (2019), who found that only 35% of respondents agreed that ICT-based agricultural helplines were a useful source of agricultural information. Furthermore, current results are inconsistent with those of Rajoria et al. (2017), who observed that even though the farmers claimed that ICT was a valuable tool for livestock extension, more than half claimed that it did not influence their decision-making.

The observation that most farmers highly perceived the proposed LMDS as a system that will save them on time and costs previously incurred in acquiring information supports the findings of Shemfe (2018), Osondu and Ibezim (2015) and Masuka et al. (2016). Previously, Aker (2011) and Osondu and Ibezim (2015) reported that ICTs, particularly mobile phones showed great potential to facilitate communication through the smooth exchange of information between various actors in agriculture. Moreover, the finding that farmers perceived that the LMDS was useful for engaging with researchers, connecting with markets, and keeping farm records may be explained by the fact that most mobile services, for instance, that allow access to market data or the capturing of farm records, are easily accessible through advanced smartphone features (Krell et al., 2021). The farmers perceived that the proposed innovation would be helpful for timely and easy access to information and extension services, possibly because of the anticipated reduction of travel times and improved access to services in real-time (Subramanian, 2021). In relation to the statements suggesting limitations in the use of the LMDS, low proportions of the respondents agreed with the statements implying the farmers have high regard for the technology. Most farmers disagreed with the statement that they would not be able to use the LMDS due to a lack of digital skills, perhaps because most farmers have gained skills through ICTs use such smartphones (Sekabira et al., 2012) and the high education level that most farmers had (Masuka et al., 2016). Most farmers disagreed with statements suggesting that they might not use LMDS because smartphones and data would be costly. This may be because many farmers already have smartphones and subscribe to an average of ZAR740 per month to connect to the internet and call extension officers. In addition to the positive assessment of the LMDS through farmers' perceptions, the results of the WTP study further revealed a very high level of users' appreciation of the innovation. Thus, all farmers were willing to accept the LMDS technology, which suggests a clear understanding of the innovation and how it will help them improve livestock management. A recent study by (Hidrobo et al., 2020) found that farmers had positive WTP for accessing digital-based agricultural and nutrition services. In a study by (Loki et al., 2020), 98% of land reform beneficiaries agreed to pay for extension services, suggesting the potential for commercially oriented smallholder farmers to pay for new technologies. Given that the farmers are on average, spending nearly ZAR800 on airtime and data, they could afford to pay a yearly subscription for accessing the LMDS, which has the potential to promote the sustainability of their system. For those farmers who cannot pay a full subscription fee, cost-sharing (Anandajayasekeram et al., 2007; Kaur and Kaur, 2018) arrangements with the government could be viable options, especially where the government gradually pulls out as the farmer scales up.

The observed significant influence of smartphone ownership on farmers' perceptions of the LMDS may be because smartphone owners had already experienced mobile technology's role and importance in accessing information and services. Mobile devices are already considered important tools for communication, collaboration, information gathering, and sharing (Lattemann and Khaddage, 2013). This finding supports the previous results of Kabir (2015) and Shemfe (2018), who reported that perceptions and adoption of digital technologies were influenced by farmers' knowledge and access to ICT information. A study by Gagnon et al. (2012) showed that ICT adoption among end-users was influenced by the clear perception of the benefits of the innovation (system usefulness). Sekabira et al. (2012) noted that this is because increased experience in using ICTs enables farmers to acquire better skills and develop more interest to use complex technologies that are efficient. Interestingly, Agholor and Ogujiuba (2021) found that access to ICTs in agriculture was significant, while awareness of ICTs in agriculture was not significant in influencing the adoption behaviour of smallholder farmers towards ICTs.

The finding that farmers' experience, was associated with their perceptions of the usefulness of the LMDS is consistent with the literature (Agholor and Ogujiuba, 2021; Kariasa and Dewi, 2015). According to Kariyasa and Dewi (2013), farmers with practical farming experience can utilise the knowledge accumulated over the years to evaluate technologies and make informed decisions. Despite farming experience being more associated with years of service at a farm or farming system, farmers can gain more experience by attending training courses and linking up with other farmers and experts, which can increase the accuracy of their perceptions towards new technologies.

The finding that education level is an important determinant on farmer perceptions of the proposed LMDS conforms with previous studies (Agholor and Ogujiuba, 2021; Kabir, 2015; Massresha et al., 2021; Shemfe, 2018). These studies maintained that education levels significantly contribute to how the farmers perceive and embrace ICT-based technologies. For instance, the finding that education influenced how farmers perceived the usefulness of the LMDS in accessing information agrees with (Krell et al., 2021). Education level was an important driver of the use of information and services delivered through mobile phones by farmers. The underlying belief is that educated farmers may have a better ability to perceive, understand, interpret and respond to new technologies than less-educated farmers (Aldosari et al., 2019; Masuka et al., 2016) and have good access and skills to use them (Atiso et al., 2021).

The significant influence of cattle herd size on farmers' perceptions of the proposed technology might be because farmers with more cattle have higher demands for agricultural information and better markets and services, which they anticipate accessing through mobile technologies (Kibona and Yuejie, 2021; Montshwe, 2006). In the view of (Masuka et al., 2016), the influence of herd sizes could be because cattle indicate a farmer's level of wealth. Therefore, farmers with more cattle can afford to use mobile ICTs. In conformity, previous studies showed that large herd sizes promoted technology adoption as they raised the farmers' financial stand to afford new technologies (Abay et al., 2016; Massresha et al., 2021). The result is evident that perception towards new technologies is a function of herd sizes; hence one of the ways to promote innovativeness among farmers is to help them grow their herd sizes.

The observed significant positive effect of gender on farmers' perceptions towards the usefulness of the proposed mobile technology conforms with many previous studies (Krell et al., 2021; Meso et al., 2005). This finding can be attributable to the fact that men and women differ in their perceptions of technologies (Meso et al., 2005). Thus, Venkatesh and Morris (2000) noted that men's technology use decisions are primarily influenced by their perception of usefulness, while women's decisions are influenced by their perception of the technology's ease of use. Therefore, in this current study assessing the perceptions of usefulness, men had higher perceptions than women. Nevertheless, findings were contrary to those of Masuka et al. (2016), who discovered that gender had no significant influence on the need by farmers to use mobiles in agriculture. Given the limited participation of women in technologies like mobile Apps for agriculture (Edwards et al., 2014; Henze and Ulrichs, 2016), the study used the recommendation in (Krell et al., 2021), which suggested not only to consider age, location and education in characterising the digital gender gap but to also consider additional drivers to mobile technology adoption like participation in farmer organisations and smartphone ownership. Based on the current findings, if the various factors identified in this study are broadly representative, they may positively impact farmers' perceptions of technologies. It is, therefore, imperative to account for them when introducing ICT-based strategies for improving the sustainability of the farmers.

The study assessed the challenges that might hinder the adoption and use of the proposed LMDS. The current finding that some farmers, especially within rural areas, had unstable network connectivity agrees with the literature (Kabir, 2015; Smidt, 2021; Trendov et al., 2019). Shemfe (2018) and Rajoria et al. (2017) showed that 55% and 30% of farmers had poor access to network connectivity in the studied areas. Reports by AGRA (2015), Messenger (2018), and Trendov et al. (2019) showed that unavailability and limited connectivity of mobile and internet services are critical limitations to the adoption and use of ICT-based technologies, especially by smallholder farmers in remote areas.

As more and more digital technologies aimed at the agricultural sector are coming on the market, digital skills are becoming an essential element of modern farm management. Some farmers indicated that lack of digital skills is one of the constraints to the adoption and use of the LMDS, and this is consistent with many studies (Henze and Ulrichs, 2016; Khan et al., 2019; Misaki et al., 2018). The studies indicated that lack of digital skills reduced the opportunities for smallholder farmers to access agricultural information and services in real-time. The current study discovers that only a few respondents perceived mobile data costs and acquiring smartphone devices as significant challenges to the usefulness and adoption of the LMDS. This is contrary to Shemfe (2018), who observed that 73 and 71% of respondents indicated that data bundles and ICT tools were expensive to purchase. The difference in findings is likely because commercially oriented smallholders in the current might be having more income, which allows them to cover the costs than subsistence smallholders studied in (Shemfe, 2018).

5.4 Qualitative results

The following themes and sub-themes were identified.

Theme1: Farmers' experiences with agricultural extension delivery systems
Theme 1.1: Sources and modes of delivery of agricultural extension services
Theme1.2: Challenges with the public extension services
Theme 2: Farmers' experiences with access and use of mobile phones and mobile applications
Theme 3: Farmers' perceptions of the proposed LMDS
Theme 3.1: Perceived usefulness towards livestock production
Theme 3.2: Farmers' WTP for the LMDS
Theme 3.3: Perceived LMDS adoption challenges and proposed solutions for addressing them

5.4.1 Theme 1: Farmers' experiences with agricultural extension delivery systems

5.4.1.1 Theme 1.1: Sources type of services and modes of delivery of agricultural extension services

Most farmers reported that they relied on the government for agricultural extension services, while a few mentioned using private extension services or full-time farm managers. Farmers mentioned that they received the agricultural extension and advisory services through farm visits by extension officers and by making phone calls and visiting extension offices. Farmers reported that typically, they will call or send a WhatsApp message to an extension officer to arrange a meeting on the farm or at the office, depending on the extension officer's schedule. The following quote is evidence of the main source and the channel used for receiving extension services by the farmer.

"……the system we always have is that our extension services come from the government. This is through the likes of Mr XXX and his colleagues. They sometimes visit my farm and help me with questions I might be having. It could be on management or production issues……we call to meet them, and we sometimes rely on WhatsApp to get updates from them."

Extension officers agreed that their primary role is to provide farmers with technical advice on animal husbandry practices, farm management, cattle marketing, infrastructural development, and natural disaster management. They reported that by visiting farms, they could identify specific challenges reported and demonstrate how to address them. Besides farm visits, the extension officers mentioned that they organise information days, farmers' days, and field demonstrations to extend technical advice to farmers or meet with industry stakeholders. However, they have temporarily stopped these due to the COVID-19 travelling and gathering ban. They also mentioned creating WhatsApp groups that they use to communicate with the farmers. Therefore, the role of extension officers in the delivery of extension services if evidenced by the quote;

"… We provide technical advice to the farmers on a daily basis by visiting their farms. Its technical advice in terms of animal production, in the areas of; nutrition, animal breeding, marketing, animal selection and so on. We also do demonstrations on technical aspects like ear tagging, branding, or ear notching. Normally, we call them as a group of ten and demonstrate to them. We do farmers' days or information days where we link our farmers with external stakeholders or call the specialists like NWK, University of North West, and ARC, so that they can demonstrate new ideas and programmes……"

Generally, the extension workers concurred with farmers.

5.4.1.2 Theme 1.2: Challenges with the public extension services

Some farmers expressed dissatisfaction with the public extension system. They mentioned that they were concerned primarily by extension officers' low visibility and poor response rate. Some of the incidences mentioned by farmers include officers not attending scheduled farm visits or arriving late. Nevertheless, some respondents acknowledged that some of these problems were not caused by the officers but were related to other problems with beyond the officers' influence. This is evidenced by one of the farmers who noted,

"…….in my case, if I am asked how often officers get to me, the answer would be once a year, and this looks bad, and no one wants to understand why….. if the department does not hire more officers, the issue cannot be rectified. This all starts with the budget allocated to agriculture. Agriculture is the largest sector with the most potential to secure income, but why is its budget allocation so low?"

This respondent was trying to identify some of the underlying problems affecting the efficiency of the officers in delivering services. Some farmers mentioned that extension officers should be increased in farming their communities, and that their transport facilities should be improved.

Extension officers mentioned that lack of transport, lack of human resources and poor road networks to reach the farms affected their ability to deliver services to the farmers. Some extension officers reported that they share one car as a group of four to visit different farmers. The interviewed key informants as agricultural extension advisors mentioned that each was serving an average of 150 farmers but field extension officers, they supervise can reach up to 400 farmers. One extension officer highlighted that failure to meet with many farmers is partly attributed to the low number of kilometres, mobile data, and airtime allocated to them. It was mentioned by extension workers that, the unavailability of data on the available farms, challenges facing the farmers every day, livestock species and numbers in their areas and farmer performances were constraining their decision making. This is evidenced by this Quote;

"… They cut the travelling kilometres of the extension officers on the ground who are expected to visit the farmers because they are trying to cut costs. How do you deal with the service delivery in that situation because the resources are not there? Then you also have the issue of airtime and data. We get 1 gig for the whole month; we do not have landlines that we can rely on for a stable internet connection.

You have to hotspot your laptop using the cell phone with only one gig……. you can't even communicate properly with the farmers. The other major problem is if take the Agricultural Advisors and you want statistics…. you will struggle to know how many animals are there and what is happening in terms of marketing, how much and where are the farmers marketing. So, with just the statistics, it's a struggle and this affect how we make decisions ……"

5.4.2 Theme 2: Farmers' experiences with access and use of mobile phones and mobile applications: Access and use of mobile phones and mobile applications

Participants made the observation that most farmers owned mobile phones. They concurred that communal subsistence farmers mostly owned basic non-internet phones, while the commercially oriented smallholders had smartphones, with some also having computers. Some of the farmers indicated that they were using mobile applications and were having laptop computers. However, some of them could not recall the actual names of the Apps. A few farmers mentioned Facebook App as one of their platforms to harness information, primarily through the Nguni cattle page. Furthermore, one of the farmers was quoted,

"……. *besides, WhatsApp, I like to use Linkedin and an animal feed mixing App which I normally connect to using my laptop."*

Extension officers concurred that most commercially oriented farmers had smartphones and laptops. However, they mentioned that smartphones and laptops were owned and efficiently used by the most productive farmers and former professionals from various disciplines such as agriculture and education. All extension officers agreed to having their own smartphones and laptops, which they received from the government. Extension officers noted that they were a few Apps related to agriculture which them and the farmers were using. These include *Animal improvement App (*general livestock production information*)*, *Voermoer* (feed mixing calculations), *Field area measures* (measuring farm size). Famers indicated that WhatsApp was the most important app facilitating communication among farmers and between farmers and extension personnel. This was supported by most extension officers who indicated that they even created WhatsApp groups such as *Agristata group 2*, which they used to relay information, discuss farmers' issues, make announcements, and share information such as market prices. One of the extension officers, when asked about the Apps being used, responded;

"We mainly use WhatsApp to share and discuss things. For example, yesterday, there was a discussion on one of my groups with farmers, Maboloka. We were discussing how to handle broilers this coming winter with farmers advising one another on how to go about the process."

Extension officers identified the *Digital pen*, also called the *Smartpen*, as one of the latest Apps the DALRRD launched to improve and monitor extension personnel's service delivery. The pen, however, they indicated that they were no longer using it because it was too difficult to operate. Some respondents noted that they could not understand some of the tool's features because they were not involved in its development process. The frustration by the extension officers regarding the digital pen is evidenced by the quote;

"……. I have been in the private sector for 10 years, and there, they are too advanced than the government itself. ……. I got exposed to some good industry related Apps there………now it was just this stupid Digital pen that wasted a lot of money from the government because there were so many limitations with it and other lots of problem…… it was frustrating us, so, it's something that even farmers cannot use…. they don't develop these things to be user friendly, they just decide this is what you want and give it to you, no, consultation…."

5.4.3 Theme 3: Farmers' perceptions of the proposed LMDS

5.4.3.1 Theme: 3.1 Perceived usefulness towards livestock production

FGDs show that farmers had positive perceptions on the usefulness of the proposed LMDS. Only a few farmers mentioned that they do not fully agree with the usefulness of the LMDS as a source of agricultural information and services as they cited digital skills issues. Generally, they viewed it as an important tool that will help them improve on livestock production. Farmers mentioned that the system is an opportunity to develop their farming systems through information sharing, access to markets, record keeping, cooperative work among themselves, and real-time communication with extension officers. Farmers indicated that using the system will allow them access to better markets which enable them to sell directly to various consumers and make more income rather than only dealing with abattoirs and auctions. One of the farmers noted,

"According to me, this app will be useful because we can use it to receive and share the information which will be valuable to us. On the app, we will gain lots of important information because we live in different districts, we can learn a lot from each other without missing out on any information."

The key informants expressed confidence in the LMDS and indicated that it would benefit them and the farmers. They stressed that the innovation will be instrumental in allowing the farmers to work collaboratively and helping each other, especially when they are unavailable to help. Asked about the potential of the LMDS, one of the extension officers further stated,

"Remember, farmers should not always rely on extension officers. If I fail to visit them, they can use the platform to ask other farmers for information, and if they can interact as farmers, it helps to form a unity among themselves."

Additionally, the extension officers revealed that, given the lack of data on the farms they have in the province, number and characteristics of farmers, and livestock numbers, the LMDS could be used to build a livestock database. Also, they mentioned that the proposed technology will reduce travel times and costs of visiting farmers while increasing the number of farmers served in a given period.

5.4.3.2 Theme 3.2: Farmers' WTP for the LMDS

When asked how much they were WTP, the farmers could not provide exact estimates. The majority of them indicated that paying to access the LMDS would not be a problem as long as it met their needs.

"……. this question is difficult for me. I can pay any amount for this as long as I see value in it. So, like we are saying, let us see its value then we talk about prices."

The research findings from extension officers show some mixed perceptions, especially on the WTP by the farmers. Some indicated that they were confident that the farmers would pay for LMDS as long as the technology was beneficial to them. Other extension officers believed that some farmers might struggle to pay because they are used to government assistance with some indicating a 50-50 chance. The mixed reactions from the extension officers are evidenced by these two quotes from different respondents;

"If you come up with a system and it's working, they will receive it with both hands. Like I have just said to you, digital pen for me, no! COVID App and PESI App, yes! So, in terms of paying a subscription fee, if it provides all these services, I think they are going to pay for it, if they can get what they want."

".....i think in this case our farmers have learnt to be assisted with almost everything. In most cases, they got that perception that everything which has to be paid, has to be done by the department, so the farmers themselves, they are not expected to pay anything."

Among the key recommendations highlighted by both farmers and extension officers was the need to recruit more young people into farming and train all farmers in in using the ICTs in line with 4IR. This was envisaged to promote the WTP of the farmers.

5.4.3.3 Theme 3.3: Perceived LMDS adoption challenges and recommendations for addressing them

In terms of challenges that might hamper the adoption of the LMDS, most farmers mentioned low digital skills due to illiteracy and old age among some farmers. They also mentioned network connectivity and the language barrier as some can only converse effectively in local languages. However, farmers with lower skill levels reported that they had family members with good smartphone operating skills. For example, when asked to comment about skills level during FGDs, one of the farmers stated;

"...I don't use technologically advanced phones because I do not have the skills. I use a simple phone that makes calls, that is all. But I have a son who can assist me with other technical issues like mobile Apps, so there will not be a problem from my side."

The extension officers concurred with the challenges mentioned by farmers. They indicated that the challenge of digital skills and language was high among communal farmers than the commercially oriented smallholders. Some of these respondents, also presented the challenge of poor network connectivity, which they indicated was severe in some parts of the province.

In terms of solutions and recommendations, all respondents (farmers and extension officers), agreed that farmers require an easy-to-operate system that operates in the local languages to ensure most farmers can access the technology. They also recommended that the responsible government departments and mobile network companies ensure stable mobile connectivity in farming areas to reduce the challenge of poor connectivity. One of the extension officers indicated that, the innovation has to be data free so that the farmers can only be charged during downloading of the App.

"…Farmers need to change; they need to adapt but cannot adapt quickly. They can adapt slowly because some are old……we need, therefore, to get these young people into agriculture so that we can work hand in hand with the old farmers so that they can assist their parents in adopting these systems."

5.4.4 Discussion of qualitative results

Regarding theme 1.1, "Sources, type of services and modes of delivery of agricultural extension services," it was confirmed in both the FGDs and KIIs, that the public extension system is the most common source of agricultural information and services for the sample farmers. Many studies show that this is the case for smallholder livestock farmers in developing countries (Eicher, 2007; Raidimi and Kabiti, 2019). In South Africa, the government's DALRRD, through its provincial departments, has a de facto monopoly over the provision of extension and advisory services to smallholder farmers (Akpalu, 2013; DALRRD, 2014; Loki et al., 2020). The current finding that extension officers provide technical advice to farmers through farm visits conforms with literature (Duvel, 2000; Hanyani-Mlambo, 2002; Loki et al., 2020).

In some countries where public extension is managed through the T&V approach, it is often integrated with other approaches, such as commodity-based extension, which are self-financed and supported by non-governmental organisations (Kidane and Worth, 2016; Swanson and Rajalahti, 2010). In South Africa, such a merger is also being used, especially in driving the government's policy of promoting indigenous genetic resources like the Nguni cattle (Gwala et al., 2016; Mapiye et al., 2018). However, given that public extension is provided free of charge (Koch and Terblanché, 2013), the farmers who indicated using private extension services or technical managers could be the ones who are more productive and have a high income since the private extension is expensive (Taye, 2013). For this reason, interventions that revolutionise public extensions and allow them to continue providing services to smallholder farmers at minimum costs are essential (Qiang et al., 2012; Tsan et al., 2019). Also, the finding from KIIs that the delivery of extension services through information days and field demonstrations were disrupted by the COVID-19 pandemic (Kerr, 2020; Siche, 2020) implies the need for mobile-based innovations like the LMDS where farmers do not need to travel or gather.

In relation to theme 1.2, “Challenges with the public extension services,” the findings show that some farmers showed dissatisfaction with the system, and this resonates with literature (Cook et al., 2021; FAO, 2017; Gwala et al., 2016; Henze and Ulrichs, 2016; Trendov et al., 2019). The reported lack of access to extension officers implies that farmers fail to receive timely and tailored assistance and cannot effectively feedback to the extension system (Van Schalkwyk et al., 2017). The lack of access to extension services may be a result of the low extension practitioner to farmer ratio, which was about 1:>300 based on the data collected to identify key informants. Since the public extension system is based on a training-and-visit approach (Akpalu, 2013; Loki et al., 2020), this low officer-to-farmer ratio further reduces the number of farmers served per year (Liebenberg, 2015). Due to a lack of services, most smallholder farmers face challenges reducing their sustainability (DALRRD, 2014; Myeni et al., 2019). The limitations of lack of transport, mobile data and airtime were also affecting the efficiency of the officers because they could not reach out to as many farmers as they would like to or as they could. These findings conform to many previous studies (Davis and Terblanche, 2016; Liebenberg, 2015; Meena and Singh, 2013), showing that public extension systems are heavily under-resourced, over-stretched, lacking human resources, and facing an overall decline in investment. Having limited access to farmer and livestock data negatively affects extension officers’ decisions, especially when structuring strategies to address the needs of farmers. These extension-related challenges formed important insights that will be used in designing the proposed LMDS to meet the actual needs of the farmers and extension officers.

Digital technology innovations related to mobile applications have seen an increased focus in the farming sector in recent years (Kenny and Regan, 2021). This has changed how smallholder farmers are profiled, how their needs are understood and met, how their data is shared, and how agricultural services are contextualised (Gray et al., 2018). Since a partially mixed sequential research method approach (Hanson et al., 2005) was adopted, the quantitative results were validated using qualitative findings (Bryman, 2003).

Considering theme 2, “Farmers’ experiences with access and use of mobile phones and mobile applications,” the qualitative results confirmed that all farmers owned mobile phones as concluded from the quantitative results. According to quantitative results, most farmers owned smartphones, and some also had laptops. The same finding was revealed with FGDs and KIIs. The study results are consistent with the gradual growth in mobile phone usage among smallholder farmers and rural people in SSA (GSMA, 2020; Masuka et al., 2016; Qiang et al., 2012), especially in economically stable countries like South Africa (ICASA, 2020). According to key informants, most farmers with smartphones and laptops were educated and had professional backgrounds, such as teaching, lecturing, and business management, indicating that those with high incomes and education could afford the tools. A few Apps were identified to be used by farmers and extension officers from both quantitative and qualitative results. However, qualitative results show that the number of Apps that farmers knew were far less than the ones they were using.

It was observed that WhatsApp was the primary application used for exchanging information. A study by (Thakur et al., 2017) points out that WhatsApp is one of the most important tools with unique advantages, making it a potent agricultural extension tool. The extension officers had experiences of using applications, with the digital pen being the latest. However, they cited many challenges associated with the tool, such as not being user-friendly. They were not consulted during the development of the system, which could have contributed to its poor acceptance and scalability. (Edwards et al., 2014) point out that most existing mobile-based tools being designed gradually lose relevance, even at the idea generation stage. Such development often considers market characteristics but fails to consider users’ contexts, values, needs, and expectations (Henze and Ulrichs, 2016; Ingram and Gaskell, 2019; Misaki et al., 2018). Thus, user perceptions of the usefulness of the innovation may indicate its future adoption and be a guide to identifying important design issues for the technology (Massresha et al., 2021); hence should be assess prior to innovation development.

With reference to theme 3.1, “Perceived usefulness towards livestock production,” most FGD respondents perceived the LMDS as an effective innovation to improve their livelihoods, mainly through access to more lucrative markets for Nguni cattle. Access to markets for Nguni cattle is one of the critical challenges undermining the development of the farmers (Malusi et al., 2021; Mapiye et al., 2018). These findings were in accord with quantitative results, which showed a strong positive perception of the usefulness of the proposed LMDS towards livestock production by the farmers. In the quantitative study, farmers had high scores for the technology's positive contribution and a low score for its limitations. The farmers' perceptions possibly stem from the understanding that the LMDS will allow them to work together in overcoming many barriers, including access to markets that keep them from reaching commercial scale (Malusi et al., 2021; Sikwela, 2013). Collective action or collaboration is widely considered a vital foundation to help smallholder farmers overcome many constraints affecting them (Sikwela, 2013). On the other hand, key informants expressed high regard for the LMDS, indicating that it will help the farmers access extension services and reduce their workload.

Furthermore, they acknowledged that farmers are a vital source of information and should work together, especially on small matters that do not require much expertise. This will allow them to focus on critical issues and develop strategic plans that promote the growth of the farmers. Also, the role of the technology in cutting costs of delivering extension and speeding the process of conveying messages to the farmers was greatly acknowledged. However, during FGDs, a few respondents were unable to agree on the usefulness of the LMDS, which could have been because they did not have the required mobile phones or did not understand how the information and services are accessed (Aldosari et al., 2019). Therefore, the department of agricultural extension should take steps to educate farmers about the importance of the LMDS to their livestock farming.

Regarding theme 3.2, “Farmers' WTP for the LMDS," the FGDs and KIIs findings showed mixed perceptions with some farmers and extension officers not uncomfortable to provide the actual WTP prices for the LMDS. The farmers requested to assess the technology first before providing an estimate of their willingness to pay subscription fees. This observation is consistent with the previous findings of (O'Donnell, 2013), where farmers and farmer groups indicated that they would only pay for ICT technology when the information provided was accurate and relevant. A study by, Hidrobo et al. (2020)

observed that most farmers were price-sensitive as they were willing to pay a low monthly price to access ICT-based services.

The current farmer's hesitation in paying for the technologies could be because such ICT innovations were still new to them; hence they were not prepared to financially commit themselves before seeing how they work or bring to them. This is because farmers' adoption behaviour cannot be easily changed as most of their operations are dependent on established long-standing relationships and systems. To support these findings, the key informants indicated that the farmers would pay, but some might fail to pay because they were used to the government providing funding to such programmes. Therefore, the qualitative observations could not fully support the quantitative study results and could create risks if not fully explored. The Esoko mobile app initially failed to scale because the data and information it provided were inaccurate, stale, and the farmers could not use it (Asare-kyei, 2013; Van Schalkwyk et al., 2017). Therefore, the LMDS prototype must be created to test this risk with farmers. Insights from such prototyping could also help develop a viable business model. The government, for example, can pay for those farmers who cannot afford the system until a certain period and gradually phase out as the farmers develop.

Regarding theme 3.3, "Perceived LMDS adoption challenges and proposed solutions for addressing them," the challenges that may reduce the farmers' adoption or use of the technology were explored, and the qualitative findings validated the quantitative results. Lack of digital skills, especially among older farmers, and poor mobile network connectivity were identified as limitations to the full use of the LMDS by both FGDs and KIIs. Consequently, farmers might struggle to use the tool, so improving network connectivity and the digital skills of farmers should be prioritised. It was also mentioned that family members with digital skills could be part of the training and deployment of the technology so that they can support farmers with low skills.

5.5 Conclusions

The study assessed commercially oriented livestock farmers and extension officers' experiences of using ICTs and their perceptions of the usefulness of the proposed LMDS in livestock management and delivering extension services. The study findings illustrate that all farmers had cell phones, with the majority having smartphones and skills to operate the gadgets, which suggest the likelihood of farmers adopting mobile-based technologies. Results from individual farmer interviews, FGDs and KIIs demonstrated that the respondents had positive perceptions towards the proposed ICT-based system. The chi-square analysis indicated that education level, smartphone ownership, farmers' experience, cattle herd size and gender were significantly associated with farmer perceptions of the usefulness of the LMDS. Understanding the determinants of user perceptions towards technology is essential in designing and developing technologies that meet the users' needs and should therefore be considered when introducing the LMDS. Important constraints that were perceived to hamper the adoption of the LMDS technology include poor network connectivity and lack of digital skills among some farmers. Limited network connectivity has implications for the adoption and usability of the technology by the farmers and extension and should therefore be addressed. Lack of skills could be averted by conducting user training programmes. Overall, the study results provide key insights which help researchers, development agents and policymakers understand users' attitudes and perceptions towards the LMDS and similar technology, which may help in facilitating adoption and diffusion of such technologies.

5.6 References

Abay KA, Berhane G, Taffesse AS, et al. (2016) *Understanding farmers' technology adoption decisions: Input complementarity and heterogeneity*. 82. Addis Ababa. Available at: http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/130163.

Adesina AA and Baidu-Forson J (1995) Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso and Guinea, West Africa. *Agricultural Economics* 13(1): 1–9. DOI: https://doi.org/10.1016/0169-5150(95)01142-8.

Agholor IA and Ogujiuba K (2021) Information Communication Technology: Perception and Adoption of Drought Resilience Strategy for Producers in Driekoppies, South Africa. *Journal of Critical Reviews* 8(02): 1220–1234.

AGRA (2015) *Africa Agriculture Status Report 2015. Youth in Agriculture in Sub-Saharan Africa*. Nairobi. Available at: http://www.agra.org/media-centre/news/africa-agriculture-status-report--2015-/.

Aker JC (2011) Dial " A " for Agriculture: A Review of Information Communication Technologies for Agricultural Extension in Developing Countries. *Agricultural Economics* 42(269): 631–647. DOI:

https://doi.org/10.1111/j.1574-0862.2011.00545.x.

Akpalu DA (2013) Agriculture Extension Services Delivery in a Semi-Arid Rural area in South Africa: The Case Study of Thorndale in the Limpopo Province. *African Journal of Food, Agriculture, Nutrition and Development* 13(4). Available at: https://www.ajol.info/index.php/ajfand/article/view/94600.

Aldosari F, Al Shunaifi MS, Ullah MA, et al. (2019) Farmers' perceptions regarding the use of Information and Communication Technology (ICT) in Khyber Pakhtunkhwa, Northern Pakistan. *Journal of the Saudi Society of Agricultural Sciences* 18(2). King Saud University & Saudi Society of Agricultural Sciences: 211–217. DOI: 10.1016/j.jssas.2017.05.004.

Alomia-Hinojosa V, Speelman EN, Thapa A, et al. (2018) Exploring farmer perceptions of agricultural innovations for maize-legume intensification in the mid-hills region of Nepal. *International Journal of Agricultural Sustainability* 16(1): 74–93. DOI: 10.1080/14735903.2018.1423723.

Anandajayasekeram P, Davis K and Workneh S (2007) Farmer Field Schools: An Alternative to Existing Extension Systems? Experience from Eastern and Southern Africa. *Journal of International Agricultural and Extension Education* 14(1): 81–93. DOI: 10.5191/jiaee.2007.14107.

Asare-kyei D (2013) *Mobile Agriculture : Providing Tools and Support for Market Information Services and Commodity Price Exchange*. Geneva. Available at: https://unctad.org/system/files/non-official-document/SUC_GCF2013_18-03-2013_Daniel-ASARE-KYEI.pdf.

Atiso K, Folitse BY and Manteaw SA (2021) Mobile Telephony and Agriculture Information Communication in Ghana: the Ho West District under Review. *Library Philosophy and Practice* 2021(January): 1–28.

Baruah A and Mohan M (2018) The Farmers ' View Towards the Use of Information and Communication Technology in Agriculture : A Study Among Farmers in the Ner (North- Eastern Region) of India. *Journal of Emerging Technologies and Innovative Research (JETIR)* 5(11): 17–23.

Batchelor S, Scott N, Manfre C, et al. (2014) Is there a role for mobiles to support sustainable agriculture in Africa? In: *ICT for Sustainability 2014, ICT4S 2014*, Stockholm, 2014, pp. 272–280. DOI: 10.2991/ict4s-14.2014.33.

Bizikova L, Brewin S, Bridle R, et al. (2020) *The Sustainable Agriculture Transition :Technology options for low- and middle-income countries*. Winnipeg. Available at: https://www.iisd.org/system/files/2020-08/sustainable-agriculture-transition-technology.pdf.

Braun V and Clarke V (2006) Using thematic analysis in psychology Using thematic analysis in psychology. *Qualitative Research in Psychology* 3(2): 77–101. DOI: http://dx.doi.org/10.1191/1478088706qp063oa.

Bryman A (2003) *Quantity and Quality in Social Research* (M Bulmered.). 2nd ed. London and New York: Routledge. DOI: 10.4324/9780203410028.

Choudhary AK and Suri VK (2013) On-Farm Participatory Technology Development Effects on Resource Conservation Technologies in Rainfed Upland Paddy in Himachal Pradesh, India. *Communications in Soil Science and Plant Analysis* 44(17): 2605–2617. DOI: 10.1080/00103624.2013.811521.

Cook BR, Satizábal P and Curnow J (2021) Humanising Agricultural Extension: A review. *World Development* 140. The Author(s): 105337. DOI: 10.1016/j.worlddev.2020.105337.

Creswell JW (2014) *Research Design: Qualitative, Quantitative and Mixed Methods Aproaches*. 4th ed. Washington DC: SAGE Publications.

DALRRD (2014) *National Policy on Eextension and Advisory Services*. Pretoria, South Africa.

Daum T, Buchwald H, Gerlicher A, et al. (2018) Smartphone apps as a new method to collect data on smallholder farming systems in the digital age : A case study from Zambia. *Computers and Electronics in Agriculture* 153. Elsevier: 144–150. DOI: 10.1016/j.compag.2018.08.017.

Davis FD (1989) Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly: Management Information Systems* 13(3): 319–339. DOI: https://doi.org/10.2307/249008.

Davis KE and Terblanche SE (2016) Challenges Facing the Agricultural Extension Landscape in South Africa, Quo Vadis? *S. Afr. J. Agric. Ext.* 44(2): 231–247. DOI: http://dx.doi.org/10.17159/2413-3221/2016/v44n2a428.

Dehnen-Schmutz K, Foster GL, Owen L, et al. (2016) Exploring the role of smartphone technology for citizen science in agriculture. *Agronomy for Sustainable Development* 36(2): 1–9. DOI: 10.1007/s13593-016-0359-9.

Deressa TT, Hassan RM, Ringler C, et al. (2009) Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change* 19(2). Elsevier Ltd: 248–255. DOI: 10.1016/j.gloenvcha.2009.01.002.

Duvel GH (2000) Towards an Appropriate Extension Approach for Agricultural and Rural Development in South Africa. *South African Journal of Agricultural Extension* 29(1): 10–23.

Edwards B, Tassi R, Tse L, et al. (2014) *mAgri Design Toolkit: User-centered design for mobile agriculture*. United Kingdom. Available at: https://www.comminit.com/ict-4-development/content/magri-design-toolkit-user-centered-design-mobile-agriculture.

Eicher CK (2007) *Agricultural Extension in Africa and Asia*. 48824. Michigan.

Emeana EM, Trenchard L and Dehnen-Schmutz K (2020) The revolution of mobile phone-enabled services for agricultural development (m-Agri services) in Africa: The challenges for sustainability. *Sustainability* 12(1): 485–490. DOI: 10.3390/su12020485.

FAO (2009) *The Technology Challenge*. Rome. Available at: https://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Technology.pdf.

FAO (2017) *Information and Communication Technology (ICT) in Agriculture: A Report to the G20 Agricultural Deputies*. Rome: Food and Agriculture Organisation. Available at: www.fao.org/publications.

Feder G and Umali DL (1993) Special Issue Technology and Innovation In Agriculture and Natural ResourcesThe adoption of agricultural innovations. *Technological Forecasting and Social Change* 43(3): 215–239. DOI: https://doi.org/10.1016/0040-1625(93)90053-A.

Gagnon MP, Desmartis M, Labrecque M, et al. (2012) Systematic review of factors influencing the adoption of information and communication technologies by healthcare professionals. *Journal of Medical Systems* 36(1): 241–277. DOI: 10.1007/s10916-010-9473-4.

Gray B, Babcock L, Tobias L, et al. (2018) *Digital Farmer Profiles: Reimagining Smallholder Agriculture*. *United States Agency for International Development*. Available at: https://www.usaid.gov/sites/default/files/documents/15396/Data_Driven_Agriculture_Farmer_Profile.pdf.

GSMA (2020) *The mobile Economy: Sub-Saharan Africa 2020*. United Kingdom. Available at: https://www.gsma.com/mobileeconomy/wp-content/uploads/2020/09/GSMA_MobileEconomy2020_SSA_Eng.pdf.

Gwala L, Monde N and Muchenje V (2016) Effect of Agricultural Extension Services on Beneficiaries of the Nguni Cattle Project: The Case Study of two Villages. *Applied Animal Husbandry & Rural Development* 9: 31–40.

Hanson WE, Plano Clark VL, Petska KS, et al. (2005) Mixed methods research designs in counseling psychology. *Journal of Counseling Psychology* 52(2): 224–235. DOI: 10.1037/0022-0167.52.2.224.

Hanyani-Mlambo B (2002) *Strengthening the Pluralistic Agricultural Extension System: A Zimbabwean Case Study*. Rome. Available at: http://www.fao.org/3/AC913E/ac913e00.htm.

Henze J and Ulrichs C (2016) The potential and limitations of mobile-learning and other services in the agriculture sector of Kenya using phone applications. In Proceedings of the 12th European International Farming Systems Association (IFSA) Symposium, Social and Technological Trans. In: Shropshire, UK, 2016, pp. 1–11. International Farming Systems Association (IFSA). Available at: https://www.harper-adams.ac.uk/events/ifsa/papers/2/2.5 Henze.pdf.

Hidrobo M, Palloni G, Aker JC, et al. (2020) *Paying for Digital Information: Assessing Farmers' Willingess to Pay for Digital Agriculture and Nutrition Service in Ghana*. *Teaching Cultural Economics*. Washington DC. DOI: 10.4337/9781788970747.00039.

ICASA (2020) *The state of the ICT sector in South Africa 2020*. Johannesburg. Available at: https://www.icasa.org.za/uploads/files/State-of-the-ICT-Sector-Report-March-2020.pdf.

Ingram J and Gaskell P (2019) Searching for meaning: Co-constructing ontologies with stakeholders for smarter search engines in agriculture. *NJAS - Wageningen Journal of Life Sciences* 90–91(May). Elsevier: 100300. DOI: 10.1016/j.njas.2019.04.006.

Jha S, Kaechele H, Lana M, et al. (2020) Exploring farmers' perceptions of agricultural technologies: A case study from Tanzania. *Sustainability (Switzerland)* 12(3): 1–21. DOI: 10.3390/su12030998.

Joshi A, Kale S, Chandel S, et al. (2015) Likert Scale: Explored and Explained. *British Journal of Applied Science & Technology* 7(4): 396–403. DOI: 10.9734/bjast/2015/14975.

Kabir KH (2015) Attitude and Level of Knowledge of Farmers on ICT based Farming. *European Academic Research* 2(10): 13177–13196.

Kariasa K and Dewi YA (2015) Analysis of factors affecting adoption of integrated crop management farmer field school (Icm-Ffs) in swampy areas SCHOOL (ICM-FFS) IN SWAMPY AREAS. *International Journal of Food and Agricultural Economics* 1(2): 29–38. DOI: 10.22004/ag.econ.160092.

Kariyasa K and Dewi YA (2013) Analysis Of Factors Affecting Adoption Of Integrated Crop Management Farmer Field School (Icm-Ffs) In Swampy Areas. *International Journal of Food and Agricultural Economics* 1(2): 29–38.

Kassem HS, Alotaibi BA, Ghoneim YA, et al. (2021) Mobile-based advisory services for sustainable agriculture: Assessing farmers' information behavior. *Information Development* 37(3): 483–495. DOI: 10.1177/0266666920967979.

Kaur K and Kaur P (2018) Agricultural Extension Approaches to Enhance the Knowledge of Farmers. *International Journal of Current Microbiology and Applied Sciences* 7(2): 2367–2376. DOI: https://doi.org/10.20546/ijcmas.2018.702.289.

Kenny U and Regan Á (2021) Co-designing a smartphone app for and with farmers: Empathising with end-users' values and needs. *Journal of Rural Studies* 82(January): 148–160. DOI: 10.1016/j.jrurstud.2020.12.009.

Kerr WA (2020) The COVID-19 Pandemic and Agriculture: Short- and Long-run Implications for International Trade Relations. *Canadian Journal of Agricultural Economics* 68: 225–229. DOI: 10.1111/cjag.12230.

Khan NA, Qijie G, Ali S, et al. (2019) Farmers' use of mobile phone for accessing agricultural information in Pakistan: A case of Punjab province. *Ciencia Rural* 49(10). Universidade Federal de Santa Maria. DOI: 10.1590/0103-8478cr20181016.

Kibona CA and Yuejie Z (2021) Factors that influence market participation among traditional beef cattle farmers in the Meatu District of Simiyu Region, Tanzania. *PLoS ONE* 16(4): 1–14. DOI: 10.1371/journal.pone.0248576.

Kidane TT and Worth SH (2016) Different Agricultural Extension Systems Implemented in Africa: A Review. . *Journal of Human Ecology* 55(3): 183–195. DOI: https://doi.org/10.1080/09709274.2016.11907022.

Kitinya KT, Onwonga RN, Onyango C, et al. (2012) Climate Change and Variability: Farmers ' Perception , Experience and Adaptation Strategies in Makueni County , Kenya. *Asian Journal of Agriculutre and Rural Development* 2(3): 411–421. DOI: http://dx.doi.org/10.22004/ag.econ.197987.

Kivunike FN, Ekenberg L, Danielson M, et al. (2011) Perceptions of the role of ICT on quality of life in rural communities in Uganda. *Information Technology for Development* 17(1): 61–80. DOI: 10.1080/02681102.2010.511698.

Koch B and Terblanché S (2013) An Overview of Agricultural Extension in South Africa. *South African Journal of Agricultural Extension* 41(1): 107–117.

Krell NT, Giroux SA, Guido Z, et al. (2021) Smallholder farmers ' use of mobile phone services in central Kenya. *Climate and Development* 13(3). Taylor & Francis: 215–227. DOI: 10.1080/17565529.2020.1748847.

Lattemann C and Khaddage F (2013) A Review of the Current Status of Mobile Apps in Education - Implication for Emerging Country's Business Education Strategy. *Innovation in Business Education in Emerging Markets* (January 2016): 1–269. DOI: 10.1057/9781137292964.

Liebenberg F (2015) *Agricultural Advisory Services in South Africa*. Pretoria.

Loki O, Mudhara M and Pakela-Jezile Y (2020) Factors influencing farmers' use of different extension services in the eastern cape and Kwazulu-Natal provinces of South Africa. *South African Journal of Agricultural Extension (SAJAE)* 48(1): 84–98. DOI: 10.17159/2413-3221/2020/v48n1a528.

Malusi N, Falowo AB and Idamokoro EM (2021) Herd dynamics, production and marketing constraints in the commercialization of cattle across Nguni Cattle Project beneficiaries in Eastern Cape, South Africa. *Pastoralism* 11(1). Pastoralism: 1–12. DOI: 10.1186/s13570-020-00186-x.

Mapiye O, Makombe G, Mapiye C, et al. (2018) Limitations and prospects of improving beef cattle production in the smallholder sector: a case of Limpopo Province, South Africa. *Tropical Animal Health and Production* 50(7). Springer Netherlands: 1711–1725. DOI: 10.1007/s11250-018-1632-5.

Mapiye O, Makombe G, Mapiye C, et al. (2019) Management information sources and communication strategies for commercially oriented smallholder beef cattle producers in Limpopo province, South Africa. *Outlook on Agriculture* 49(1): 50–56. DOI: 10.1177/0030727019860273.

Massresha SE, Lema TZ, Neway MM, et al. (2021) Perception and determinants of agricultural technology adoption in North Shoa Zone, Amhara Regional State, Ethiopia. *Cogent Economics and Finance* 9(1). Cogent. DOI: 10.1080/23322039.2021.1956774.

Masuka B, Matenda T, Chipomho J, et al. (2016) Mobile phone use by small-scale farmers: a potential to transform production and marketing in Zimbabwe. *South African Journal of Agricultural Extension (SAJAE)* 44(2): 121–125. DOI: 10.17159/2413-3221/2016/v44n2a406.

Maunganidze F, Bonnin D and Ruggunan S (2021) Economic Crisis and Professions: Chartered Accountants in Zimbabwe. *SAGE Open* 11(1). DOI: 10.1177/2158244021994802.

Mchugh ML (2013) The Chi-square test of independence Lessons in biostatistics. *Biochemia Medica* 23(2): 143–9. Available at: http://dx.doi.org/10.11613/BM.2013.018.

Meena MS and Singh KM (2013) *Pluralistic Agricultural Extension System in India: Innovations and Constraints*. 48324. Munich. Available at: http://mpra.ub.uni-muenchen.de/48324/.

Meijer SS, Catacutan D, Ajayi OC, et al. (2015) The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. *International Journal of Agricultural Sustainability* 13(1). Taylor & Francis: 40–54. DOI: 10.1080/14735903.2014.912493.

Meso PN, Musa PF and Mbarika VW (2005) Towards a model of consumer use of mobile information and communication technology in LDCs: The case of sub-Saharan Africa. *Information Systems Journal* 15(2): 119–146. DOI: 10.1111/j.1365-2575.2005.00190.x.

Messenger C (2018) Digital Insights Malawi: Information and Communication in Rural Communities. Malawi: DAI.

Misaki E, Apiola M, Gaiani S, et al. (2018) Challenges facing sub-Saharan small-scale farmers in accessing farming information through mobile phones: A systematic literature review. *Electronic Journal of Information Systems in Developing Countries* 84(4): 1–12. DOI: 10.1002/isd2.12034.

Montshwe BD (2006) *Factors affecting participation in the main stream cattle markets by small-scale farmers in South Africa.* University of Free State. Available at: https://scholar.ufs.ac.za/handle/11660/1833.

Moore DS, Notz WI and Leysieffer F (2013) *The Basic Practice of Statistics.* 6th ed. New York city: W.H. Freeman and Company. DOI: 10.2307/2589073.

Mwangi M and Kariuki S (2015) Factors Determining Adoption of New Agricultural Technology by Smallholder Farmers in Developing Countries. *Journal of Economics and Sustainable Development* 6(5). Available at: www.iiste.org.

Myeni L, Moeletsi M, Thavhana M, et al. (2019) Barriers Affecting Sustainable Agricultural Productivity of Smallholder Farmers in the Eastern Free State of South Africa. *Sustainability* 11: 3003. DOI: 10.3390/su11113003.

Neuman LW (2007) *Basic of Social Research Qualitative and Quantitative*. 2nd ed. Boston: Pearson education.

O'Donnell M (2013) *Using ICT to Enhance Marketing for Small Agricultural Producers*. *USAID Briefing Paper*.

Available at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0CDQQFjAB&url=https://communities.usaidallnet.gov/ictforag/file/417/download/686&ei=UaJRU8ujBLPesASoz4H4Bg&usg=AFQjCNEwikPjRTZIGkl-VZtywDgNPlfLuw&sig2=MFIyw%0Ahttps://www.g.

Ogutu SO, Okello, Julius J and Otieno DJ (2014) Impact of Information and Communication Technology-Based Market Information Services on Smallholder Farm Input Use and Productivity : The Case of Kenya. *World Development* 64. Elsevier Ltd: 311–321. DOI: 10.1016/j.worlddev.2014.06.011.

Osondu CK and Ibezim GMC (2015) Awareness and perception of farmers to the use of Information and Communication Technologies (ICTs) in agricultural extension service delivery: a case study of Imo State, Nigeria. *International Journal of Agriculture Innovations and Research* 4(1): 55–60. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=lah&AN=20153325118&site=ehost-live%5Cnhttp://www.cabi.org/cabdirect/showpdf.aspx?PAN=http://www.cabi.org/cabdirect/showpdf.aspx?PAN=20153325118%5Cnhttp://www.ijair.org/administrator/components/com_jres.

Qiang CZ, Kuek SC, Dymond A, et al. (2012) *Mobile Applications for Agriculture and Rural Development*. Washington DC.

Raidimi EM and Kabiti HM (2019) A Review of The Role of Agricultural Extension and Training in Achieving Sustainable Food Security: A Case of South Africa. *South African Journal of Agricultural Extension* 47(3): 120–130. DOI: http://dx.doi.org/10.17159/2413-3221/2019/v47n3a520.

Rajoria S, Kumar Rewani S, Singh V, et al. (2017) Constraints Perceived by Livestock Farmers in Use of ICTs in Jaipur District of Rajasthan, India. *International Journal of Current Microbiology and Applied Sciences* 6(12): 1834–1839. DOI: 10.20546/ijcmas.2017.612.208.

SAS Institute (2012) SAS/STAT User's Guide. 9.3. New York city.

Sekabira H, Bonabana J and Asingwire N (2012) Determinants for adoption of information and communications technology (ICT)-based market information services by smallholder farmers and traders in Mayuge District , Uganda. *Journal of Development and Agricultural Economics* 4(14): 404–415. DOI: 10.5897/JDAE12.081.

Shemfe OA (2018) *Evaluation of Small- scale Farmers ' use of Information Communication Technology for Farm Management in Mahikeng Local Municipality*. North West University.

Siche R (2020) What is the impact of COVID-19 disease on agriculture? *Scientia Agropecuaria* 11(1): 3–9. DOI: 10.17268/sci.agropecu.2020.01.00.

Sikwela MM (2013) *the Impact of Farmer Support Programmes on Market Access of*. University of Fort Hare.

Smidt HJ (2021) Factors affecting digital technology adoption by small-scale farmers in agriculture value chains (AVCs) in South Africa. *Information Technology for Development*. Taylor & Francis: 1–27. DOI: 10.1080/02681102.2021.1975256.

Subramanian A (2021) Harnessing digital technology to improve agricultural productivity? *PLoS ONE* 16(6 June 2021): 1–17. DOI: 10.1371/journal.pone.0253377.

Swanson BE and Rajalahti R (2010) *Strengthening Agricultural Extension and Advisory Systems: Procedures for Assessing, Transforming, and Evaluating Extension Systems*. *Agriculture and Rural Development*. 44. Washington DC. Available at: http://siteresources.worldbank.org/INTARD/Resources/Stren_combined_web.pdf.

Taherdoost H (2018) A review of technology acceptance and adoption models and theories. In: *Interdisciplinary Engineering*, Tirigu-Mures, 2018, pp. 960–967. Elsevier B.V. DOI: 10.1016/j.promfg.2018.03.137.

Taye H (2013) Evaluating the impact of agricultural extension programmes in sub-Saharan Africa: Challenges and prospects. *African Evaluation Journal* 1(1). DOI: 10.4102/aej.v1i1.19.

Thakur D, Chander M and Sinha S (2017) Whatsapp for Farmers : Enhancing the Scope and. 6(4): 2190–2201.

Trendov N, Varas S and Zeng M (2019) *Digital technologies in Agriculture and Rural Areas*. Rome. DOI: 10.4324/9780429507533-13.

Tsan M, Totapally S, Hailu M, et al. (2019) *The Digitalisation of African Agriculture: Report 218-219*.

Wageningen.

Van Schalkwyk F, Young A and Verhulst S (2017) *Ghana's Esoko: Leveling the Information Playing Field for Smallholder Farmers*. Available at: http://odimpact.org/files/case-esoko.pdf.

Venkatesh V and Morris MG (2000) Why don't men ever stop to ask for directions? Gender, social influence, and their role in technology acceptance and usage behavior. *MIS Quarterly: Management Information Systems* 24(1): 115–136. DOI: 10.2307/3250981.

Wyrzykowski R (2020) *Mobile connectivity in Sub-Saharan Africa: 4G and 3G connections overtake 2G for the first time*. United Kingdom. Available at: https://openknowledge.worldbank.org/handle/10986/19032

Chapter 6: On the development of a Livestock Management Database System Prototype and its implementation mechanisms: A Design Thinking approach

Abstract

This chapter describes how the LMDS application suite was designed and developed. A human-centred Design Thinking (DT) approach was employed. The first stage of the DT process involved learning and understanding the targeted users' experiences, needs and expectations through observing, engaging, and empathising with them. This was achieved through individual interviews and focus group discussions with farmers and key informant interviews with extension officers. This was followed by an intense process of redefining the challenges into insights which were used to create features of the LMDS solution. Findings show that farmers lacked access to relevant information and services and could not share experiences with fellow farmers or provide feedback to extension officers. They had limited access to formal markets due to a lack of timely and accurate marketing information and the absence of animal and farm records. Therefore, the main insight observed was that the farmers needed a user-driven, efficient, cost-effective tool to access extension services and researchers, share experiences with fellow farmers, keep farm records, and participate in previously unexplored high-value markets. The results also show that the extension officers were heavily affected by very low extension to farmer ratio and shortage of support resources for conducting farm visits resulting in fewer farmers being served. Also, the extension system experiences a weak linkage with researchers and farmers and lacks statistical data on livestock production at local and provincial levels, which affects the development of solutions that fit farmers' needs. Therefore, the DALRRD needs a pluralistic, user-driven and efficient tool to increase the extension officer-to-farmer ratio, reduce costs of delivering services, strengthen the farmer-extension-research, and access a livestock database of all farmers to improve services delivery. Through these insights, a minimum viable product (MVP) of the LMDS is developed to meet the needs of end-users and achieve product-market fit.

6.1 Introduction

The implementation of user-centric technology development initiatives is gaining momentum but has remained one-dimensional and is based on user participation after the development of the technology (Ingram and Gaskell, 2019; Misaki et al., 2018). Thus, various agricultural development programmes engage the end-users by mainly soliciting their feedback on tool performance and ease of use (Ingram et al., 2016; Rose et al., 2018). However, other studies drawing from a multidimensional perspective have shown that active and direct involvement of end-users iteratively from design up until adoption could increase the relevance and value of the solution intervention towards the users' needs (Danes et al., 2014; Edwards et al., 2014; Macken-Walsh, 2019). For example, (Oliver et al., 2017) indicated using a stakeholder-driven approach to develop a decision support tool to visualise *Escherichia coli* risk on agricultural land. The study used feedback from targeted users and other stakeholders to understand how the tool could be adjusted to ensure it was in line with user preferences. In a study in Italy, Rossi et al. (2014) observed that the involvement of vineyard farmers in developing their decision tool enabled researchers to gain insights into their decision-making ways, especially how the tool could fit into their decision-making routines. These examples show that user-centred design approaches put farmers and their experience at the centre of the product and service design. They are grounded on continuous and structured interaction with end-users. This approach is very similar to the New Public Governance (NPG) theory in Public Administration and Management (Osborne et al., 2013) which espouses the co-production of services between service providers (municipalities) and beneficiaries of service delivery (municipal residents). In a similar way the user-centric approach is replacing the market-centric approach to technology design, the NPG replaced the New Public Management (NPM) theory in Public Administration and Management (Nkuna and Sebola, 2012) which was more market-centric. This is evidence that this shift is not only happening in technology design but in other fields.

The DT process is one such influential approach to conceptualising human-centred technology design approaches, especially those targeting to be adopted by farmers (Edwards et al., 2014). The heart of the approach is to understand the customer, implying that all ideas and subsequent work stem from knowing the customer. It has also gained importance in the past few years because of its multidimensional nature, as the challenges of achieving both farmer sustainability and the technology's business viability have become more complex and uncertain (Sanders and Stappers, 2014; Storni et al., 2015). It is noteworthy that there is a lack of studies and development initiatives promoting the implementation of human-centred DT processes in developing mobile-based agricultural interventions specifically for smallholder farmers in Africa and particularly in South Africa. Edwards et al. (2014) noted that many mobile-based agricultural tools marketed to smallholder farmers or emerging markets had encountered low user adoption despite being offered by leading mobile network operators and value-added services providers. As a result, this research study adopted a human-centred and iterative DT framework in developing the LMDS application system for use by farmers and the public extension system in South Africa.

The LMDS technical development process is ongoing. It started with the innovation being disclosed at Innovus, where it was agreed that it was a potentially commercially viable proposition. Innovus is a division of Stellenbosch University responsible for technology transfer, entrepreneurial support and development, of innovation-centred student research at the university. The LMDS innovation was assessed and found to be commercilisable, therefore, the company is coordinating the development of the LMDS prototype which leads to commercialisation and the creation of a spinout company. Innovus is coordinating the development of the LMDS through its technology transfer management system.

6.2 A synopsis of the DT framework

Design thinking methodology today is well known as a powerful problem-solving tool often used in business organisations for generating innovative solutions and improving creative confidence (Holubchak, 2020). At its core, it is a human-centred approach to innovation. According to Gerber (2006), DT is a systematic process that individuals or teams can use to understand users' deep-rooted needs to create valuable product or service outcomes. Thus, it asks the technology designers to leave their assumptions and hypotheses at the doorstep and embrace the beginner's mindset. Companies and research institutions worldwide apply this human-centred approach to business and research practices (Brown and Wyatt, 2010; IDEO, 2011). Although it seems like a relatively new concept, (Johansson-

Sköldberg et al., 2002) indicated that the history of DT began way back in the 1960s. However, the major academic discussion began when the DT concept was identified as an essential process for creating artefacts in the 1970s (Michalos and Simon, 1970).

Kwon et al. (2021) how that many different institutions in both industry and academia have come up with models of DT. For example, The Design Council (the British Council) suggested a double diamond model that consists of four phases, all starting with the letter D: (i) discover; (ii) define; (iii) develop; (iv) deliver. Thus, this process incorporates two stages for divergence and another two for convergence. The mobile-Agri Design toolkit identified a five-phased model: (i) plan, (ii) learn, (iii) create, (iv) develop and (v) maintain (Edwards et al., 2014). IDEO is the leading company in using and continuously evolving DT methods. Its fundamental model, called the 3I model, has been covered countless times in online academic courses. The 3I model consists of the following phases: (i) inspiration, (ii) ideation, and (iii) implementation. Finally, the most well-known model is Stanford school's five-step DT, which consists of (i) empathising, (ii) definition, (iii) ideation, (iv) prototyping, and (v) testing stages. The approach has been adopted by various technology developing companies and training institutions such as Stellenbosch University's Launch lab. This study adopted this model, and Figure 6.1 presents a schematic representation of the model stages. As prescribed by Mononen (2017), these stages did not necessarily proceed on a linear timeline in developing the LMDS, as the stages were often part of an iterative process.

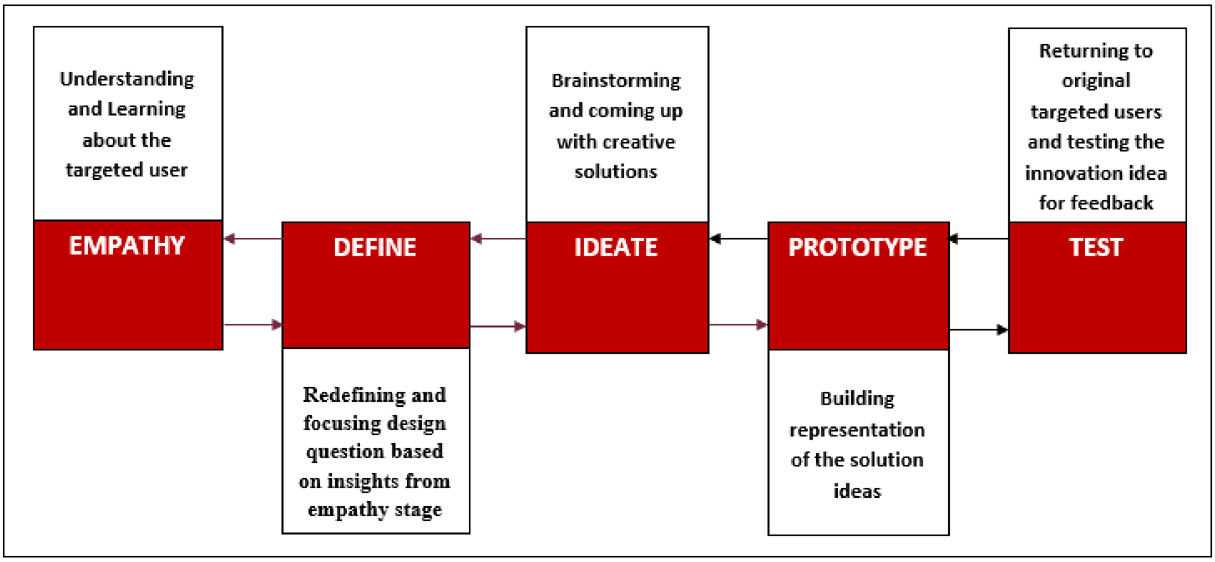

Figure 6.1 The design thinking framework used for the study based on the Stanford school's five-step

6.3 Methodology

The study site and methods used are discussed in Chapter 3.

6.3.1 Empathising

The first step in building the LMDS start-up was to empathise with targeted users (Figure 6.1). It is the centrepiece of a human-centred design process, as it serves to gain an empathic understanding of the problem under investigation. In the current study, this stage involved consulting with farmers and extension officers to understand more about them through observation and engagement (Alhamdani, 2016). Therefore, empathy extends beyond merely including users in a design process to considering their articulated needs, thoughts, emotions and motivations (Kenny and Regan, 2021).

Data collection consisted of individual farmers interviews, FGDs with farmers and KIIs with extension officers as described in Chapter 3 and 6. Data captured on questionnaires and transcripts were transferred to a Customer Discovery with Empathy tool in an Excel spreadsheet. The tool had a hypothesis page that illustrated hypothetical challenges facing farmers and extension officers and a customer discovery pipeline that captured the actual, more profound challenges facing farmers and extension officers based on the interviews conducted. In order to empathise with respondents, the research questions for individual interviews and FGDs were designed to (1) identify where and how farmers access extension information and services; (2) rate the performance of the public extension; (3) report challenges faced in accessing extension services; (4) where and how they market their animals; and (5) report marketing challenges experienced. KIIs guide sought to identify (1) methods used to deliver extension services and their adequacy; (2) challenges faced in delivering extension services to farmers; (3) marketing and other constraints faced by farmers; and (4) explore the possibility of farmers and extension officers adopting LMDS.

6.3.2 Data analysis

All quantitative data from individual interviews were subjected to descriptive statistics using the PROC FREQ procedure of Statistical Analytical System (SAS Institute, 2012). Qualitative data were analysed by following a framework of the thematic analysis as described in Chapter 5.

6.3.2.1 Defining user challenges

The customer discovery start-up hypothesis tab with empathy information was reviewed to assess whether the user engagement findings differed from the stated hypotheses. Following a thorough synthesis, the designers defined and reframed all observations and the users' unmet needs to identify the pain points to be addressed (Holubchak, 2020; Kwon et al., 2021). Thus, an empathy map was completed to break out what the respondents say, do, and feel. This stage helped the designers develop great ideas, establish features, functions, and any other elements that will allow them to solve the problems or, at the very least, enable targeted users to solve issues themselves. These underlying issues facing the targeted users were developed into user Point of View (POV) statements. Appendix 4 shows the template used for developing the POV statements. The POV statements were the meaningful and actionable problem statements that allowed for the brainstorming of the features of the LMDS.

6.3.2.2 The ideation process

The next step was the ideation process, which involved the generation of innovative features of the solution to meet targeted user problems (Kwon et al., 2021). The ideation process involved all technology developing team brainstorming possible solutions to the defined challenges. This was achieved by transforming or reframing all the User POVs into simple How Might We (HMW) statements and questions that would attract more creativity to strengthen the characteristics of the intervention (Figure 6.2). As a result, various innovative ideas were suggested to strengthen the LMDS innovation.

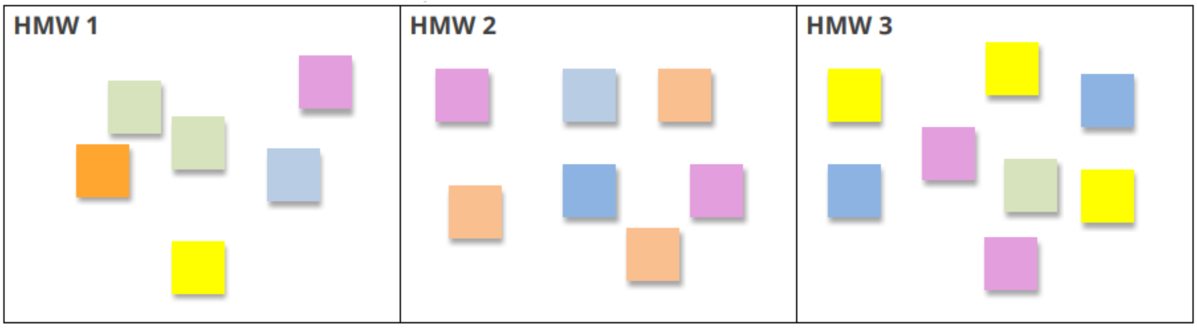

Figure 6.2 Brainstorming the various solutions to the HMW statements

6.3.2.3 Building the Business Case

A business model canvas technique was developed, which answered the three broad questions; (1) Do they want it (human desirability)? (2) Can we do it (technical feasibility)? and (3) Should we do it (business viability)? These questions were further divided into nine components with more specific questions as presented in Appendix 5. A business model canvas shows the rationale of how the implementation of the LMDS will create, deliver and capture value to targeted users and the implementing company or institution. Data and insights for building the business canvas model were obtained from farmer interviews, consultation with industry experts and analysing the existing competitors' business models.

6.4 Results and discussion

6.4.1 The underlying constraints and needs of the farmers

The current study revealed that over 90% of the farmers rely on public extension services, while a few uses private extension or full-time farm managers. This finding corroborates Eicher (2007) and (Raidimi and Kabiti, 2019), who indicated that public extension is the largest and most common source of information for smallholder livestock farmers in developing countries. The studied farmers indicated that they mainly receive extension services through farm visits by extension officers (66%), as well as by telephoning (65%) and visiting the extension offices (38%). Despite public extension being the primary source of services, some farmers are dissatisfied with the system.

Farmers were concerned by the low visibility of extension officers (64% of respondents), with the average number of visits per year being four. Also, farmers claimed a low response rate (66%) from extension officers, citing instances of them not attending scheduled farm visits or arriving late. This causes farmers to use telephones or driving to the government offices, leading to high mobile phone bills, fuel expenses, and lost time. The limited access to extension services implies that farmers fail to receive timely and tailored assistance and cannot effectively feedback to the extension system (Van Schalkwyk et al., 2017). These farmers face complex daily choices; hence lacking information affects their decision-making, which is attested in many studies (Amer et al., 2018; Brhane et al., 2017). In addition, FGD's findings confirmed that farmers have limited channels to directly communicate or link with extension officers. The lack of communication and feedback mechanisms between farmers and agricultural experts hinders the development of solutions tailored to farmers' needs.

Besides extension services, access to markets and marketing information was indicated as a key constraint to their commercialisation. Nearly 60% rated accessibility of good markets as poor to very poor. Limited market participation by smallholder farmers is one of the longstanding critical challenges acknowledged by literature (Mapiye et al., 2018; Thamaga-Chitja and Morojele, 2014). Smallholder farmers traditionally compete with established commercial producers for market share and are often driven off the market because they do not have competitive advantages. The major challenge was the low market prices (71% of respondents), especially for the Nguni cattle. For example, one of the farmers during FGDs noted;

'If we are to take Nguni and Bonsmara cattle weaners with the same body weight and frame size to an auction, the Nguni weaners will fetch far much less than Bonsmara. We have tried to understand why it is like that, but we don't get convincing responses'

FGD results also reveal the challenges of market unreliability and discrimination against farmers. Previously, Mapiye et al. (2018) reported inconsistent pricing of live animals and inappropriate classification and pricing of carcasses as forms of market unreliability. About 33% raised the challenge of poor roads and high transport costs to the markets. Poor road networks and lack of transport often increase marketing costs, resulting in farmers not participating in high value markets.

The present study revealed that the majority of farmers rely on auction calendars (51%), own research (25%) and fellow farmers (22%) for marketing prices information. FGDs and KIIs show that the lack of reliable marketing information remains a severe challenge in South Africa's smallholder farming community. It often forces the farmer to switch from formal to informal markets (Montshwe, 2006). Based on KII findings, the low formal market participation by Nguni cattle farmers is being aggravated by the lack of animal identification and farm performance records. Not keeping up-to-date farm records often erodes the farmers' bargaining power leading to exclusion from previously inaccessible high-value formal markets. Therefore, this keeps the farmers trapped in the vicious cycle of low investment, low productivity, profitability, and stagnant growth.

6.4.2 The underlying challenges confronting public extension officers

South Africa's DALRRD, through its provincial departments, has a *de facto* monopoly over the provision of extension and advisory services (Akpalu, 2013; DALRRD, 2014; Koch and Terblanché, 2013). It has, however, remained limited in terms of transforming smallholder farmers into commercial farmers. Based on KII interviews, the main constraint facing South Africa's public extension system is the very low extension officer to farmer ratio (typically 1:>300). Considering that the extension system is based on a T & V approach, where extension officers visit farmers to provide services, the low extension officer-to-farmer ratio reduces the number of farmers serviced per year. Key informants indicated that this situation is worsened by the officers' lack of resources such as transport. It has been reported that in some areas, four extension officers use one car. These findings conform to many previous studies showing that public extension systems in developing countries are heavily under-resourced, over-stretched, lack skilled human resources and infrastructural support, and face an overall decline in investment (Baig and Aldosari, 2013; Davis and Terblanche, 2016). According to the key informants, the government introduced a digital pen that monitors and captures their activities in an attempt to improve the visibility of extension officers on farms. However, all officers indicated that they could not use the tool because it was not user friendly, and they were neither adequately trained nor were they part of its development process. One of the structural limitations highlighted during KIIs is the weak farmer-extension-research linkage. This challenge is also acknowledged in SA's public extension draft policy of 2014 (DALRRD, 2014), suggesting a need for the linkage to be strengthened.

Also, according to KIIs, the DALRRD lacks real-time data on farmer location, challenges confronting farmers, and their performance which is essential for making policy decisions and developing response strategies. Also, this extends to the lack of strategies and tools for recording and documenting indigenous technical knowledge being used and shared among farmers (World Bank, 2017).

The most important insights from the empathy-building stage were the critical challenges and constraints highlighted by farmers and extension officers. Therefore, these challenges were reframed and grouped into goals and insights to refine the targeted users' needs.

6.4.3 Reframing targeted users' challenges into insights

The POVs distilled all the valuable Customer Discovery and Empathy Building analysis results into actionable and straightforward statements used in ideating, prototyping, and testing the solution.

6.4.3.1 POV statement for the farmers

Based on the engagements, the studied farmers would like to transform their farming to commercial scale. In order to achieve this, the farmers need access to relevant farm management information, inputs, and services in real-time, which they can use to improve skills and make informed management decisions for the sustainable growth of their farming systems.

Instead of driving long distances, using excess airtime and waiting for a long time to access extension officers for advice, the farmers would like to have a user-friendly, affordable, and efficient platform for accessing the services. Through the platform, they should also be able to share skills among themselves and give feedback to the extension system by directly engaging with extension officers, veterinary personnel, local researchers and any other relevant stakeholders.

For a long time, the farmers have aspired to participate in high-value markets, sell their animals at better prices, so as to have improved cashflows and higher profits, enabling them to re-invest and increase their economic sustainability. To achieve this, they would like to have access to marketing data and information in real-time, connect with various marketing players, practice collective marketing to reduce costs and have bargaining power.

The farmers acknowledged the importance of keeping farm records in making informed decisions and the possibility of unlocking previously unexplored formal markets; hence they would appreciate to having customisable and easy to use tools for keeping farm management records and data.

Table 6.1 The POV statements for the farmers.

User POV 1

User	Needs	Insights
Commercially oriented smallholders	➢ Operational, ➢ Wide-ranging, ➢ Platform	✓ Receive timely market information, ✓ Access and link with high-value markets, ✓ Access market training and capacity building, ✓ Keep farm records, ✓ Improve farm profitability,

Commercially oriented smallholder farmers who are hardworking and passionate about livestock farming **need** an operational and wide-ranging production management and marketing platform **to produce** sustainably, have better access and link with high-value markets, receive timely production and market information, and improve record-keeping, collaborative practice action and ultimately achieve farm profitability.

User POV 2

User	Needs	Insights
Commercially oriented smallholders	➢ Farmers-driven, ➢ Efficient, ➢ User friendly, ➢ Cost effective, ➢ Tool	✓ Access timely and relevant extension services ✓ Access previously inaccessible agri-service providers ✓ Share skills and innovation with fellow farmers, ✓ Receive solutions and give feedback to extension officers and researchers

Emerging livestock farmers need a user-driven, efficient, and cost-effective tool **so that they may** have access to previously inaccessible relevant and accurate extension, research and other agri-services for improved farm productivity. They should be able to exchange management information among themselves and provide timely feedback to extension and researchers.

6.4.3.2 POV for the government extension services

The DALRRD needs to deliver pluralistic, harmonised and coordinated extension and advisory services that can effectively and efficiently drive the government's agenda of growing smallholder farming in the country. Therefore, it requires a system that can increase the number of farmers serviced by extension officers, thereby reducing farm visits.

The research-extension-farmers linkage must be strengthened to allow farmers to give feedback to the extension system and enable researchers to generate appropriate, timely and relevant solutions based on the need of farmers and requests from extension officers.

DALRRD would like to have a database that captures statistical data of all livestock farms and farming activities at the provincial or district level. The data will assist in long-term planning at policy level and the designing of customised extension services for farmers.

Table 6.2 The POV statement for the public extension services

User POV 3

User	Needs	Insights
DALRRD, Public Extension services provider	➢ User friendly, ➢ Pluralistic, ➢ User-centred, ➢ Efficient tool/s	✓ To reduce the farmer-to-extension ratio, ✓ Reduce costs of delivering extension services, ✓ Strengthen the farmer-extension-research nexus, ✓ Use a livestock database, ✓ To drive the commercialisation of smallholder farmers effectively and efficiently.

The **DALRRD,** which is mandated to provide agricultural extension and advisory services to smallholder farmers, **needs** a user-friendly, pluralistic, farmer-driven and efficient tool **so that it may** reduce the current farmer-to-extension ratio and the associated high costs of delivering services, strengthen the farmer-extension-research and access a livestock database of all farmers which all should promote the commercialisation of smallholder livestock farmers.

6.4.5 The LMDS Business Model Canvas

A business model canvas that describes the rationale of how the implementation of the LMDS will create, deliver and capture value to targeted users and the implementing company was developed. The Business Model Canvas (not shared due to IP issues) shows the desirability, feasibility, and viability of the LMDS innovation.

6.4.5.1 Customer segments, value propositions and respective business models

The LMDS has a viable short-term and medium-term business model, which allows the system to self-finance its activities and remain operational without donor reliance. The short-term business model, central to this study, targets two segments: emerging livestock farmers and the government's DALRRD in South Africa.

6.4.5.1.1 Commercially oriented smallholders

The LMDS aims to improve the growth and sustainability of emerging livestock farming systems by addressing challenges identified by this study. Its adoption and use can enable farmers access to relevant and accurate farm management information, inputs, and services, making them more efficient in managing their farming systems.

6.4.5.1.2 Department of Agriculture's extension services

The LMDS will help the DALRRD drive a pluralistic, harmonised and coordinated extension and advisory service that can effectively and efficiently drive the government's agenda of commercialising smallholder farmers. Thus, fusing the extension delivery system with the LMDS intervention can promote timely provision of services to farmers while cutting on costs of extension visits, implying, more farmers can be reached and assisted with fewer resources and time being consumed.

Once fully developed, the LMDS can also assist the DALRRD to have a database that captures statistical data of all livestock farms and farming activities at the provincial and or district levels.

6.4.5.1.3 Other livestock value chain actors

The livestock value chain in South Africa has thousands of abattoirs, auctions, feedlots, retail butcheries, transporters, input suppliers whose businesses thrive on livestock production. The LMDS's medium to long-term business model expands the targeted customer segments to include these value chain players. Thus, the system will open previously inaccessible markets to these customer segments. User engagements are ongoing to investigate the various revenue streams to unlock from these customer segments, such as subscription fees, advertising fees, and transaction fees (which may be the most viable model). Also, the local researchers will be targeted as a customer segment that could benefit through access to research data which they can use to create more value for other customer segments.

6.4.5.2 Channels

Given that the targeted farmers have a strong relationship and are beneficiaries of government programmes, the initiative will be spearheaded in partnership with the DALRRD. Partnering with the DALRRD will help harness more trust, cooperation, and acceptance of the technology by the farmers. Based on the field engagements and the awareness created with field officers at district and local municipal levels in the visited provinces, this proposed route is the most viable option.

Firstly, the LMDS prototype will be demonstrated to provincial departments of agriculture for their buy-in, followed by the Training of Trainers (TOT) programmes at the provincial level. The TOT will be a comprehensive and high-level training programme designed to build knowledge and skills among trainers on the roles and functionalities of the LMDS. The trainers recruited from the various districts will provide training, capacity assistance, and awareness during the system's deployment. This will be followed by a series of group and individual farmer training and user facilitation programs within farming communities to strengthen relationships with farmers. This first batch of well-trained lead farmers will assist the new beneficiaries within their communities as the system scales up. Through these engagements, the farmers and extension officers will be allowed to give feedback about the intervention for further improvements.

6.4.5.3 Customer relations

The LMDS system will have self-service and automated messaging facilities presented in simple and understandable language. This will allow the registered farmers to directly receive help through automated means and by querying the platform. Also, through the information exchange box, farmers can share information among themselves or with experts, which helps build professional and business relationships. The (trained) extension officers will be available to help on how to use the systems.

6.4.5.4 Key Activities

6.4.5.4.1 Data Collection, Analysis and Packaging

LMDS will be driven by the amount and quality of information compiled from various sources and how the available data is analysed and packaged to meet user needs. Thus, well-planned and timely data collection, analysis, interpretation, and packaging promote the accessibility to good quality information. Extension, veterinary, and the LMDS information officers will perform these activities.

6.4.5.4.2 Information dissemination

The general agricultural information, adverts, and various alert messages developed through the data collection, analysis, interpretation, and packaging activities will be provided to the farmers via the LMDS platform on a timely basis. The disseminated information informs farmers' production and marketing decisions in addressing challenges and effectively responding to business opportunities.

6.4.5.4.3 Market Linkages

Improved farmers' access to better or previously unexplored high-value market opportunities will be achieved by linking them with various market segments through the platform and providing timely, accurate, and usable market information. Therefore, the information about who is selling and seeking to buy will be readily available on the LMDS platform. The market linkage activity will be necessitated through a marketing hub, a component of the LMDS that links all the farmers to the market.

6.4.5.4.4 Maintaining the LMDS Platform

In order for the system to scale up and become sustainable, it has to be maintained continuously. Thus, after its launch and deployment, the main responsibilities shift from building to maintaining and upgrading it. Some important short to long-term maintenance activities include adding new features, updates based on user experiences, supporting the system with new hardware/software, updating the user interface, timely debugging, monitoring performance and offering scheduled system maintenance.

6.4.5.4.5 LMDS Platform moderation

Platform moderation and curation is essential. The purpose of this is to monitor all user-generated content, including live discussion chats among the farmers, extension agents and any other stakeholders to prevent sharing irrelevant information and services.

6.4.5.5 Key Resources

6.4.5.5.1 The LMDS Platform

The LMDS is an easy-to-follow, efficient and user-driven mobile phone application suite and web-based system which can be accessed using mobile phones and computers by both farmers and extension officers. The tool will help in delivering the value propositions for both farmers and government extension.

6.4.5.5.2 Moderators/Information officers/UX Specialists

To ensure farmers share accurate information, the LMDS will use the readily available extension officers and our information officers to offer moderation and curation services. Each district will have a moderator and/or information officer. One extension officer and one veterinary officer will be recruited from each local municipality and trained to assist with the moderation of the system. Thus, for instance, the moderators will have a bird's-eye view of needs and trends based on the information contained in LMDS and can use it to organise the market. Besides moderation, they will find ways of gathering and displaying user-generated content.

6.4.5.5.3 Other resources

The LMDS will need computers, offices and office equipment, transport resources, Intellectual Property, and financial capital.

6.4.5.6 Key Partnerships

- Even though the LMDS will be privatised, its operationalisation will include the DALRRD as a key partner with experience working with the farmers and not aiming to replace the existing extension model. Also, it will assist with farmer mobilisation and conducting demonstrations.
- The software developing company will continue to upgrade the system software based on changes and modifications suggested during demonstrations. Over time, the software developer will be involved in transferring skills and maintenance of the system software.
- NGOs, Public and Private Institutions that seek to promote smallholder agriculture

6.4.6 Prototyping

The development process has reached the prototype software development phase. Figure 6.3 shows the LMDS Technology Readiness Levels (TRL). Funding for prototyping has been acquired from Technology Innovation Agency, South Africa.

A software development company has already been engaged, and lab software development (TRL 4) has commenced. Based on the quotation from the targeted software developer, and given the system complexity and its multiple links, the development, testing, validation and full commercialisation of the system prototype is estimated to be ZAR6 million. The software development plan showing the prototype development milestones, activities and deliverables is presented in Annexure 2.

Prototype development, testing and validation will help in improving the important features of the innovation required to develop an MVP. Activities such as field demonstrations and testing in the actual operational environment will also, help increase awareness among targeted users, de-risking critical risks, and validate the product-market fit. These activities will be conducted simultaneously with the development of baseline conditions of the innovation. The baseline conditions will be used for future impact assessments and improvements of the LMDS to ensure it maintains its intended goal of graduating smallholder farmers into commercial farmers to reduce poverty and create employment. The innovation will be ready for full commercialisation when complete testing and validation and product manufacturing specifications are finalised.

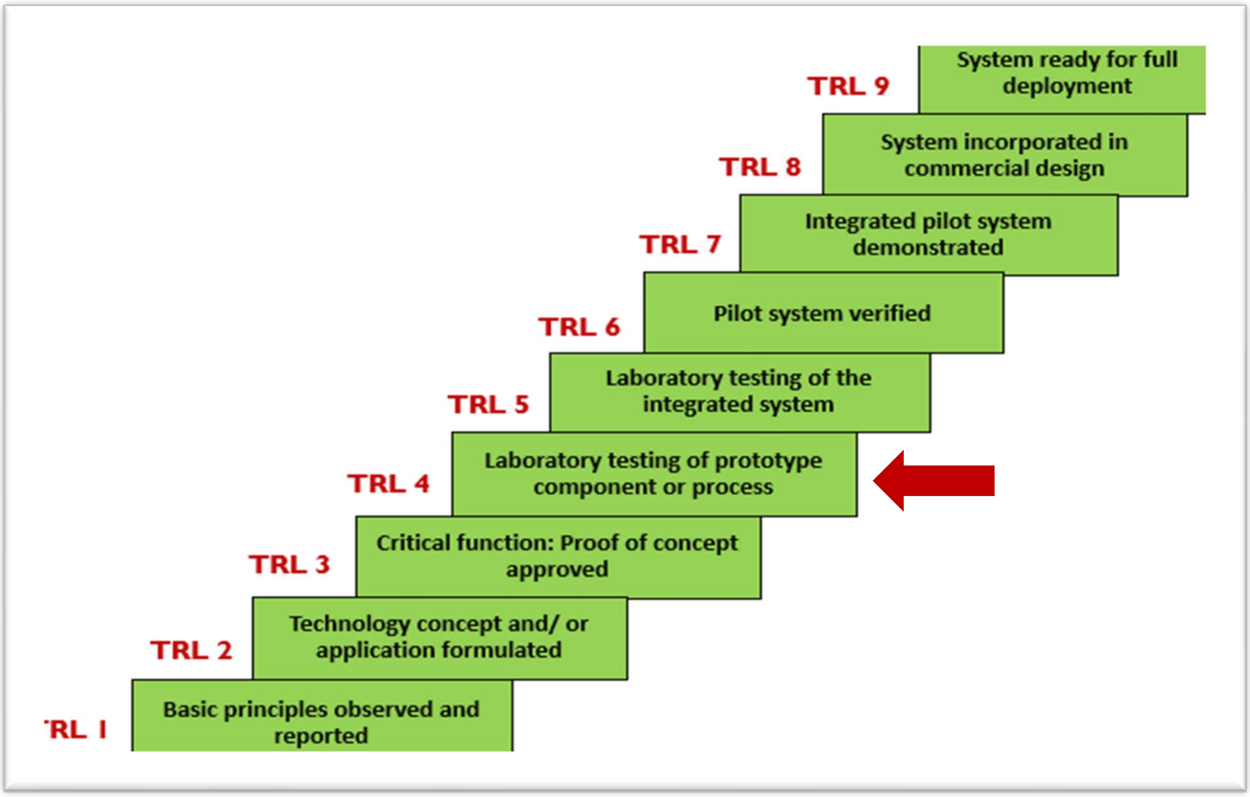

Figure 6.3 The LMDS technology readiness levels

The estimated timelines to achieve the remaining deliverables is as follows;

- Prototype software development completion: April 2022.
- Prototype testing 1 in the actual operational environment: April-May 2022

- Development of an MVP of the LMDS: July 2022
- Prototype testing 2 in the actual operational environment and baseline survey finalisation: August -October 2022
- Field deployment and full commercialisation: November 2022-7.4

6.5 Conclusion

Targeted users in this study were considered key actors who would ultimately influence and contribute to the development of the innovation rather than just be recipients and beneficiaries of the new technology. Thus, the initial engagement with farmers and extension officers helped understand their problems and the technology under development from their perspective. The study revealed that lack of relevant information, poor market access, and absence of farm records are some of the underlying challenges constraining emerging livestock farmers. The extension department suffers from a very low farmer-extension ratio, shortage of resources, weak farmers-extension-research linkage and unavailability of data on farmers. These findings were used to develop features that allow the LMDS to address the targeted user challenges. This solution strategy and concept design is being followed by the development of MVP of the LMDS. Although in progress, the actual software development process could not be discussed due to IP issues.

6.6 References

Akpalu DA (2013) Agriculture Extension Services Delivery in a Semi-Arid Rural area in South Africa: The Case Study of Thorndale in the Limpopo Province. *African Journal of Food, Agriculture, Nutrition and Development* 13(4). Available at: https://www.ajol.info/index.php/ajfand/article/view/94600.

Alhamdani WA (2016) Teaching Cryptography Using Design Thinking Approach. *Journal of Applied Security Research* 11(1). Taylor & Francis: 78–89. DOI: 10.1080/19361610.2015.1069646.

Amer J, Odero D and Kwake A (2018) Towards Improving Agricultural Marketing Information Systems for Smallholder Farmers: A Tharaka Nithi Case. *Journal of Agriculture and Sustainability* 11(2): 99–128.

Baig MB and Aldosari F (2013) Agricultural Extension in Asia: Constraints and Options for Improvement. *The Journal of Animal & Plant Sciences* 23(2): 619–632.

Brhane G, Mammo Y and Negusse G (2017) Sources of information and information seeking behavior of smallholder farmers of Tanqa Abergelle Wereda, central zone of Tigray, Ethiopia. *Journal of Agricultural*

Extension and Rural Development 9(4): 47–52. DOI: 10.5897/jaerd2016.0850.

Brown T and Wyatt J (2010) *Design Thinking for Social Innovation*. *Stanford Social Innovation Review*. Stanford, Carlifonia. Available at: http://www.ssireview.org/images/articles/2010WI_Features_DesignThinking.pdf.

DALRRD (2014) *National Policy on Eextension and Advisory Services*. Pretoria, South Africa.

Danes MHGI, Jellema A, Janssen SJC, et al. (2014) *Mobiles for Agricultural Development: Exploring trends, challenges and policy options for the Dutch government*. Alterra. Available at: http://edepot.wur.nl/297683.

Davis KE and Terblanche SE (2016) Challenges Facing the Agricultural Extension Landscape in South Africa, Quo Vadis? *S. Afr. J. Agric. Ext.* 44(2): 231–247. DOI: http://dx.doi.org/10.17159/2413-3221/2016/v44n2a428.

Edwards B, Tassi R, Tse L, et al. (2014) *mAgri Design Toolkit: User-centered design for mobile agriculture*. United Kingdom. Available at: https://www.comminit.com/ict-4-development/content/magri-design-toolkit-user-centered-design-mobile-agriculture.

Eicher CK (2007) *Agricultural Extension in Africa and Asia*. 48824. Michigan.

Gerber E (2006) Relations in design thinking: A case study of a social network. *Academy of Management Proceedings* 30(1). DOI: https://doi.org/10.5465/ambpp.2006.22898700.

Holubchak K (2020) the Application of Design Thinking Methodology in Architectural Education in Ukraine: Case Study. *Architecture, Civil Engineering, Environment* 13(4): 19–29. DOI: 10.21307/acee-2020-027.

IDEO (2011) *Design Thinking for Educators*. 2nd Editio. New York. Available at: http://designthinkingforeducators.com/.

Ingram J and Gaskell P (2019) Searching for meaning: Co-constructing ontologies with stakeholders for smarter search engines in agriculture. *NJAS - Wageningen Journal of Life Sciences* 90–91(May). Elsevier: 100300. DOI: 10.1016/j.njas.2019.04.006.

Ingram J, Mills J, Dibari C, et al. (2016) Communicating soil carbon science to farmers: Incorporating credibility, salience and legitimacy. *Journal of Rural Studies* 48: 115–128. DOI: 10.1016/j.jrurstud.2016.10.005.

Johansson-Sköldberg U, Woodilla J and Cetinkaya M (2002) License for The Stacks Project. *Creativity and Innovation Management. (Creativity and Innovation Management, June 2013, 22(2):121-146)* 22(November): 1–8. Available at: http://ezproxy.tlu.ee/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edselc&AN=edselc.2-52.0-84900312458&site=eds-live.

Kenny U and Regan Á (2021) Co-designing a smartphone app for and with farmers: Empathising with end-users' values and needs. *Journal of Rural Studies* 82(January): 148–160. DOI: 10.1016/j.jrurstud.2020.12.009.

Koch B and Terblanché S (2013) An Overview of Agricultural Extension in South Africa. *South African Journal of Agricultural Extension* 41(1): 107–117.

Kwon J, Choi Y and Hwang Y (2021) Enterprise design thinking: An investigation on user-centered design processes in large corporations. *Designs* 5(3). DOI: 10.3390/designs5030043.

Macken-Walsh Á (2019) Multi-actor co-design of extension interventions: paradoxes arising in three cases in the Republic of Ireland. *Journal of Agricultural Education and Extension* 25(3). Taylor & Francis: 245–265. DOI: 10.1080/1389224X.2019.1604390.

Mapiye O, Makombe G, Mapiye C, et al. (2018) Limitations and prospects of improving beef cattle production in the smallholder sector: a case of Limpopo Province, South Africa. *Tropical Animal Health and Production* 50(7). Springer Netherlands: 1711–1725. DOI: 10.1007/s11250-018-1632-5.

Michalos AC and Simon HA (1970) *The Sciences of the Artificial* (D Cantor-Adamsed). 3rd ed. London: The MIT Press. DOI: 10.2307/3102825.

Misaki E, Apiola M, Gaiani S, et al. (2018) Challenges facing sub-Saharan small-scale farmers in accessing farming information through mobile phones: A systematic literature review. *Electronic Journal of Information Systems in Developing Countries* 84(4): 1–12. DOI: 10.1002/isd2.12034.

Mononen L (2017) Systems thinking and its contribution to understanding future designer thinking. *Design Journal* 20(1). Routledge: 4529–4538. DOI: 10.1080/14606925.2017.1352949.

Montshwe BD (2006) *Factors affecting participation in the main stream cattle markets by small-scale farmers in South Africa.* University of Free State. Available at: https://scholar.ufs.ac.za/handle/11660/1833.

Nkuna NW and Sebola MP (2012) South Africa and the Developmental Local Gov-. *Journal of Public Adminstration* 47(1): 68–87.

Oliver DM, Bartie PJ, Heathwaite AL, et al. (2017) Design of a decision support tool for visualising E. coli risk on agricultural land using a stakeholder-driven approach. *Land Use Policy* 66(April). Elsevier: 227–234. DOI: 10.1016/j.landusepol.2017.05.005.

Osborne SP, Radnor Z and Nasi G (2013) A New Theory for Public Service Management? Toward a (Public) Service-Dominant Approach. *American Review of Public Administration* 43(2): 135–158. DOI: 10.1177/0275074012466935.

Raidimi EM and Kabiti HM (2019) A Review of The Role of Agricultural Extension and Training in Achieving Sustainable Food Security: A Case of South Africa. *South African Journal of Agricultural Extension* 47(3): 120–130. DOI: http://dx.doi.org/10.17159/2413-3221/2019/v47n3a520.

Rose DC, Morris C, Lobley M, et al. (2018) Exploring the spatialities of technological and user re-scripting: The case of decision support tools in UK agriculture. *Geoforum* 89(January). Elsevier: 11–18. DOI: 10.1016/j.geoforum.2017.12.006.

Rossi V, Salinari F, Poni S, et al. (2014) Addressing the implementation problem in agricultural decision support systems: The example of vite.net®. *Computers and Electronics in Agriculture* 100. Elsevier B.V.: 88–99. DOI: 10.1016/j.compag.2013.10.011.

Sanders EBN and Stappers PJ (2014) Probes, toolkits and prototypes: Three approaches to making in codesigning. *CoDesign*. Taylor & Francis. DOI: 10.1080/15710882.2014.888183.

SAS Institute (2012) SAS/STAT User's Guide. 9.3. New York city.

Storni C, Binder T, Linde P, et al. (2015) Designing things together: intersections of co-design and actor–network theory. *International Journal of CoCreation in Design and the Arts* 11(3–4). Taylor & Francis: 149–151. DOI: 10.1080/15710882.2015.1081442.

Thamaga-Chitja JM and Morojele P (2014) The Context of Smallholder Farming in South Africa: Towards a Livelihood Asset Building Framework. *Journal of Human Ecology* 45(2): 147–155. DOI: 10.1080/09709274.2014.11906688.

Van Schalkwyk F, Young A and Verhulst S (2017) *Ghana's Esoko: Leveling the Information Playing Field for Smallholder Farmers*. Available at: http://odimpact.org/files/case-esoko.pdf.

World Bank (2017) *ICT in Agriculture: Connecting Smallholders to Knowledge, Networks, and Institutions*. Updated Ed. Washington DC: The World Bank.

Chapter 7: General Discussion, Conclusions and Recommendations

7.1 Introduction

This chapter provides a general discussion, conclusions and recommendations for the study Areas of further study are provided. The sustainability pillars addressed by the study are discussed and explained, study limitations are explained and a timeline for the development of the LMDS is provided.

The primary aim of this research was to carry out the designing and development of a Livestock Management Database System (LMDS) for improving the sustainability of commercially oriented smallholder cattle farmers in the North West Province of South Africa. The LMDS will be a customisable and easy-to-use mobile application and web-based suite accessible through smartphones, tablets, and computers. Also, it seeks to assist South Africa' DALRRD deliver well-coordinated extension and advisory services that meet farmers' needs at minimum costs.

7.2 General discussion

The key limitations to improving the sustainability of smallholder agricultural production and the role of agricultural extension in addressing these limitations were reviewed. The identified challenges can be broadly classified into ecological, economic, social, and institutional constraints (Mapiye et al., 2018). A literature study revealed that one of the key factors affecting farmers' sustainability was a lack of timely and appropriate agricultural information and services. As a result, farmers often fail to make effective decisions when faced with everyday challenges and opportunities (Amer et al., 2018; Brhane et al., 2017). Public extension systems remain limited in providing information and services to smallholders (Davis and Terblanche, 2016; Meena and Singh, 2013). Given the limitations of public extension services and the constantly changing needs of farmers, production systems, and agricultural policy objectives, many developing countries have adopted a mix of extension practices (Loki et al., 2020) that have continuously evolved. The most common extension approaches used in Africa and South and East Asia include technology transfer approaches (Ministry-based and T&V), the commodity specialised approach, participatory extension approaches (FFS and project (integrated) approach, farming systems research and extension approach), cost-sharing approach, and education institution approach (Mapiye et al., 2021). There are widespread concerns that these extension approaches have little impact on driving the growth of smallholders. For example, South Africa's public extension is still very technology-oriented, aimed at enhancing the adoption of technology rather than improving the skills of farmers through farmer-driven approaches. Its pervasive constraints are the very low extension officer to farmer ratio (typically 1:>300) and the high demand for resources which makes the system very costly. In response to the challenges associated with extension systems, discussions on how ICTs such as mobile phones and the internet can revolutionise extension and facilitate its support towards smallholder farmers have emerged strongly (Mapiye et al., 2021).

In Chapter 2, the potential of enhancing agricultural information and services dissemination to smallholder farmers through ICTs in SSA was explored. There is a general perception of ICTs as vectors of grassroots innovation, transformation, and socio-economic growth and that they have universally improved how farmers work, access information, connect and be productive (Drafor, 2016; FAO, 2018). However, there is a dearth of compelling reviews evaluating their importance in enhancing agricultural information and services dissemination to smallholder farmers. Five existing mobile applications used for disseminating agricultural information have been evaluated based on their advantages, limitations, and potential impact on smallholder farming. These are Esoko, iCow, Community Knowledge Workers, WeFarm and DigiFarm. It was observed that some positive developments and promising impact metrics are emerging from the application of these initiatives in supporting smallholders, such as improved market linkages, access to production and weather information, and mobile banking services (Asare-kyei, 2013; Mackay, 2019; Marwa et al., 2020; Shrader et al., 2019; Van Campenhout, 2017). However, most of the technologies have remained limited. Mainly anecdotal evidence exists to support these purported positive impacts. This is mainly due to a lack of baseline conditions. Most of them still portray linear and principal-agent arrangements where farmers are content receivers as they cannot give feedback into the extension systems. End-users are often excluded in the whole technology development process, which eventually affects adoption, scalability, and replicability. The identified limitations, thus, form the basis for the development of the LMDS.

The WTP for new farming technologies by farmers is an essential component of this study. It provides a basis for introducing new interventions to the farmers to improve their sustainability. The payment for ecosystem services concept (Garbach et al., 2012; Papagallo, 2018) was employed, and the WTP of commercially oriented cattle farmers for improving their rangelands was assessed. The pricing of rangelands improvement as a signal of scarcity and unsustainable use is, invariably, perceived to promote users' willingness to conserve and improve the resource. Governments and other institutions usually pay users to implement measures to protect ecosystems (Farley, 2012); however, this concept has not been applied to protect rangeland ecosystem services under smallholder production systems with farmers themselves paying (Papagallo, 2018) This study indicates that almost all farmers were willing to pay the suggested initial bid price of ZAR165.00, with the estimated mean WTP being ZAR244.00 ha^{-1} $year^{-1}$ for improving their rangelands. This demonstrates the potential of designing and implementing strategies that allow farmers to pay for their growth and sustainability. Consequently, these findings should be carefully considered when developing sustainable rangeland regeneration and conservation strategies for smallholder farmers, but most importantly, when introducing new technologies, such as LMDS, to farmers. Farmers are willing to pay if they perceive benefit from technological interventions.

Chapter 5 aimed to investigate commercially oriented cattle producers' perceptions of the usefulness of the LMDS and identify its deployment and adoption limitations. One of the challenges associated with introducing ICTs in smallholder agriculture is the critical need to ensure that they are adopted and implemented by farmers (Jha et al., 2020; Mwangi and Kariuki, 2015). Thus, it is important to note that the decisions by farmers to adopt new agricultural innovations are not an overnight phenomenon and are dependent on various complex factors. For example, the farmers' subjective preferences regarding the innovation-specific characteristics and their perceptions, attitudes also play an important role in influencing their adoption behaviour (Massresha et al., 2021). Therefore, to make the LMDS a user-driven solution and improve farmers' adoption behaviour, it was critical to assess the farmers' subjective attitudes and perceptions regarding the technology. The majority of farmers in this study owned smartphones, had moderate to high levels of digital literacy and used the internet to search for agricultural information. The farmers and extension officers had high and positive perceptions of the usefulness of the proposed LMDS. Factors such as smartphone ownership, farmers' experience, education level, cattle herd size and farm size positively influenced farmers' perceptions. In order to increase the likelihood of adoption of the LMDS, challenges such as poor network connectivity and a lack of digital skills should be addressed. This chapter provides detailed insights into farmers' attitudes towards new technologies that researchers, development agents, and policymakers can use when developing interventions to improve farmers' sustainability.

7.3 Recommendations

The recommendations made in this chapter relate to study findings and align with the sustainability pillars discussed above. Thus, if implemented, these recommendations could significantly improve the smallholder transformation agenda of achieving economic, social, and ecological growth in their farming systems. The main recommendations are:

1. It is demonstrated that one of the main limitations of existing technologies almost similar to LMDS is the lack of baseline conditions, resulting in most of their impact studies being unreliable and inaccurate. Baseline data were not collected in this study, and it is recommended that baseline conditions be established as part of the development process of the LMDS.
2. Improvements to policy approaches (regulatory and developmental) targeted at the 4th Industrial Revolution, such as universal mobile network access, are critical elements that should be addressed to enhance the contribution of the LMDS.
3. Despite the majority of commercially oriented farmers having skills in operating smartphones, further training is required to assist them in contextualising their information sharing and direct communication skills with various experts and service providers through the LMDS platform. Moreover, national extension officers' training curricula should be reviewed to ensure they have advanced skills for using technologies like LMDS in delivering services to farmers.
4. The issue of gender disparities remains a significant challenge to the scaling of the existing agricultural applications and development of agriculture as women are often excluded from using them despite performing most of the farming activities in smallholder farming systems (Zyl et al.,

2014). Therefore, strategies at the policy level should lobby for the uptake of ICTs by women farmers and other vulnerable groups such as youths and the elderly.

5. It is recommended to engage public agencies, especially government extension, who are part of the existing programs and networks involved with smallholder farmers to ensure that farmers have trust and accept the technologies. The partnership arrangements should extend to local universities and researchers who will help evaluate technology impacts, identify areas of improvement for such technologies, and ensure they continue to support the farmers.
6. Given the farmers' positive perceptions of the LMDS further development of the LMDS to prototype and field testing is recommended.

7.4 The Sustainability pillars addressed by the study

The development of the LMDS aligns with the essential underpinning aims and objectives of sustainable agriculture. The study acknowledges the three broad dimensions underlying the concept of sustainable agriculture: economic/profitability, environmental/ecological, and social/cultural sustainability (Lebacq et al., 2013). These three pillars are inter-reliant and mutually reinforcing, suggesting that an improvement in any one leads to improvement of the other(s). This research underscores the roles that farmers and agricultural extension can and should play in achieving sustainability objectives. The LMDS will facilitate farmers' access to agricultural information and skills, which will assist them to make more informed decisions and ultimately become more sustainable.

Thus, the developed system will help farmers access accurate and reliable market information and keep farm records, enabling them to participate in previously inaccessible high-value markets. Accessing better marketing options enables the farmers to sell their produce at better market prices, have improved farm incomes, and therefore create the possibility of farmers to make investments and re-investments, leading to higher farm economic gains or improved economic profitability.

By assessing the WTP to improve rangelands, insights were gained into the potential of using the payment for ecosystem services schemes to achieve ecological sustainability under commercially oriented cattle farming systems. The information generated can be used to conduct further research and develop appropriate strategies and programmes for improving the ecological status of rangelands. Additionally, LMDS will serve as a source of information and a tool for mainstreaming agroecological practices and programmes among farmers that ensures ecological sustainability.

The study outputs contribute towards the social sustainability of farmers and farming communities. The use of the LMDS directly promotes farmer networking and, therefore, social cohesion and collective actions among them, leading to increased productivity and welfare growth. Implementation of this learning-based innovation will positively transform learning patterns and interactions between farmers and various stakeholders. As a result, rural communities can sustainably achieve viability and widespread prosperity, including developing local agriculture and other non-agricultural value chains while creating employment for women and youths.

Furthermore, the 2030 Agenda for Sustainable Development adopted by the United Nations (UN) in September 2015 sets out 17 Sustainable Development Goals (SDGs) across the social, economic, and environmental dimensions. The revolution of public extension systems and the development of smallholder farming through the use and deployment of the LMDS contribute to sustainable food security and influence five dimensions of the SDGs. These are ending poverty (SDG1), zero hunger, achieving food security and sustainable agriculture (SDG2), reducing inequality (SDG10), sustainable communities (SDG11), and responsible consumption and production (SDG12).

7.5 Areas of further study

Areas that require further research include the following:

1. Further research can be conducted to assess the implementation of the payment for ecosystems services scheme, its adoption by farmers, and possibly its impact on improving the rangelands in the long run.
2. An impact assessment study on the contribution of the LMDS to the sustainability of livestock production and the efficiency of public extension in delivering extension services merits further research after the LMDS is created. It would be insightful to perform research on the generalizability of the LMDS with other agricultural commodities or farming systems.

3. Further research to ascertain why farmers did not have ICT-based Apps for accessing agricultural services in the study area would be invaluable to the cause of smallholder agricultural development in developing countries.

7.6 Limitations of the study

A counterfactual study to assess the before-and-after implementation of the LMDS or evaluate the perceptions of various farmer groups could not be conducted. This is because the system's baseline data and functional software have not yet been developed due to a lack of financial resources and time required to develop the final product. Nonetheless, the study did not seek to test or perform counterfactual assessments but rather to provide justification and design for the intervention by exploring the perceptions of targeted users and gathering data that would inform the software development.

Some of the limitations of this study include:

1. Considering that the interviewed farmers had not used the LMDS before, their perceptions about its usefulness were hypothetical.
2. The study was based on a sample of commercially oriented smallholder cattle farmers from a running project and one province, so this may limit the generalisability of the findings.

7.7 The status of the technical development of the LMDS

The technical development process follows a human-centred design thinking process (Edwards et al., 2014). The design thinking process is a systematic, non-linear and iterative process employed to understand users, challenge initial assumptions, redefine problems presented by targeted users and create innovative features of the innovation (LMDS) to prototype and test. Its first step involved learning and understanding the targeted users' experiences, needs and expectations through observing, engaging and empathising with them. Thus, individual farmers' interviews, FGDs, and KIIs showed that farmers had challenges of limited access to agricultural information and extension services which negatively impacted their decision making. DALRRD, which is expected to provide information and services, faces limited resources, including transport, human resources and an absence of data on farms and farmers' activities. These underlying issues facing the targeted users were developed into user Point of View (POV) statements by completing the template in Appendix 4. The POV statements were the meaningful and actionable problem statements that allowed for the brainstorming of the features of the LMDS.

A business model canvas technique was developed, which answered the three broad questions; (1) Do they want it (human desirability)? (2) Can we do it (technical feasibility)? and (3) Should we do it (business viability)? These questions were further divided into nine components with more specific questions (Osterwalder et al., 2010) as presented in Appendix 5. A business model canvas shows the rationale of how the implementation of the LMDS will create, deliver and capture value to targeted users and the implementing company or institution. Data and insights for building the business canvas model were obtained from farmers interviews, consultation with industry experts and analysing the existing competitors' business models.

7.8 References

Amer J, Odero D and Kwake A (2018) Towards Improving Agricultural Marketing Information Systems for Smallholder Farmers: A Tharaka Nithi Case. *Journal of Agriculture and Sustainability* 11(2): 99–128.

Asare-kyei D (2013) *Mobile Agriculture : Providing Tools and Support for Market Information Services and Commodity Price Exchange*. Geneva. Available at: https://unctad.org/system/files/non-official-document/SUC_GCF2013_18-03-2013_Daniel-ASARE-KYEI.pdf.

Brhane G, Mammo Y and Negusse G (2017) Sources of information and information seeking behavior of smallholder farmers of Tanqa Abergelle Wereda, central zone of Tigray, Ethiopia. *Journal of Agricultural Extension and Rural Development* 9(4): 47–52. DOI: 10.5897/jaerd2016.0850.

Davis KE and Terblanche SE (2016) Challenges Facing the Agricultural Extension Landscape in South Africa, Quo Vadis? *S. Afr. J. Agric. Ext.* 44(2): 231–247. DOI: http://dx.doi.org/10.17159/2413-3221/2016/v44n2a428.

Drafor I (2016) Access to Information for Farm-Level Decision-Making. *Journal of Agricultural & Food Information* 17(4). Taylor & Francis: 230–245. DOI: 10.1080/10496505.2016.1213170.

Edwards B, Tassi R, Tse L, et al. (2014) *mAgri Design Toolkit: User-centered design for mobile agriculture*. United Kingdom. Available at: https://www.comminit.com/ict-4-development/content/magri-design-toolkit-user-centered-design-mobile-agriculture.

FAO (2018) *Gender and ICTs: Mainstreaming Gender in the Use of Information and Communication Technologies (ICTs) For Agriculture and Rural Development*. Rome: Food and Agriculture Organisation (FAO). Available at: https://www.fao.org/documents/card/en/c/I8670EN/.

Farley J (2012) Ecosystem services: The economics debate. *Ecosystem Services* 1(1). Elsevier: 40–49. DOI: 10.1016/j.ecoser.2012.07.002.

Garbach K, Lubell M and DeClerck FAJ (2012) Payment for Ecosystem Services: The roles of positive incentives and information sharing in stimulating adoption of silvopastoral conservation practices. *Agriculture, Ecosystems and Environment* 156. Elsevier B.V.: 27–36. DOI: 10.1016/j.agee.2012.04.017.

Jha S, Kaechele H, Lana M, et al. (2020) Exploring farmers' perceptions of agricultural technologies: A case study from Tanzania. *Sustainability (Switzerland)* 12(3): 1–21. DOI: 10.3390/su12030998.

Kwon J, Choi Y and Hwang Y (2021) Enterprise design thinking: An investigation on user-centered design processes in large corporations. *Designs* 5(3). DOI: 10.3390/designs5030043.

Lebacq T, Baret P V. and Stilmant D (2013) Sustainability indicators for livestock farming. A review. *Agronomy for Sustainable Development* 33(2): 311–327. DOI: 10.1007/s13593-012-0121-x.

Loki O, Mudhara M and Pakela-Jezile Y (2020) Factors influencing farmers' use of different extension services in the eastern cape and Kwazulu-Natal provinces of South Africa. *South African Journal of Agricultural Extension (SAJAE)* 48(1): 84–98. DOI: 10.17159/2413-3221/2020/v48n1a528.

Mackay S (2019) *WeFarm - Connecting Small-Scale Farmers to the People and Resources They Need to be More Successful*. United Kingdom. Available at: https://www.agrilinks.org/users/sarahlouisemackay81#profile-main.

Mapiye O, Makombe G, Mapiye C, et al. (2018) Limitations and prospects of improving beef cattle production in the smallholder sector: a case of Limpopo Province, South Africa. *Tropical Animal Health and Production* 50(7). Springer Netherlands: 1711–1725. DOI: 10.1007/s11250-018-1632-5.

Marwa ME, Mburu J, Oburu REJ, et al. (2020) Impact of ICT Based Extension Services on Dairy Production and Household Welfare: The Case of iCow Service in Kenya. *Journal of Agricultural Science* 12(3): 1–12. DOI: 10.5539/jas.v12n3p141.

Massresha SE, Lema TZ, Neway MM, et al. (2021) Perception and determinants of agricultural technology adoption in North Shoa Zone, Amhara Regional State, Ethiopia. *Cogent Economics and Finance* 9(1). Cogent. DOI: 10.1080/23322039.2021.1956774.

Meena MS and Singh KM (2013) *Pluralistic Agricultural Extension System in India: Innovations and Constraints*. 48324. Munich. Available at: http://mpra.ub.uni-muenchen.de/48324/.

Mwangi M and Kariuki S (2015) Factors Determining Adoption of New Agricultural Technology by Smallholder Farmers in Developing Countries. *Journal of Economics and Sustainable Development* 6(5). Available at: www.iiste.org.

Papagallo L (2018) *Operationalizing payments for ecosystem services for pastoralists in rangeland settings*. Montpellier. Available at: https://cgspace.cgiar.org/handle/10568/92345.

Shrader L, Mukau E and Karylyn A (2019) *DigiFarm: A Digital Platform for Farmers- Case study*.

Van Campenhout B (2017) There is an app for that? The impact of community knowledge workers in Uganda. *Information Communication and Society* 20(4). Taylor & Francis: 530–550. DOI: 10.1080/1369118X.2016.1200644.

Zyl O Van, Alexander T, Graaf L De, et al. (2014) *ICTs for Agriculture in Africa*. *eTransform Africa*. Washington DC. DOI: 10.1007/springerreference_77816.

Appendices

Appendix 1: Survey Questionnaire

INDIVIDUAL FARMER QUESTIONNAIRE

Smallholder livestock farmers' performance, sustainability, and perceptions on the usefulness of ICT-based in improving livestock production and access to agricultural extension services

PARTICIPANT CONSENT

I, …………………………………………….………….., agree to take part in the survey. The interviewer has fully explained the purpose of the survey and the fact that my responses will be strictly confidential. I voluntarily participate in the study, and I will not receive any compensation for taking part.

Signature…………………………Date: ……………………………

Farmer's name……………………………………………….
Name of farm………………………………………………..
Farmer's Tel No ……………………………..……………

Province ………………………………….
Municipality ……………………………
Enumerator name ………………………

A. FARMER SOCIO-ECONOMIC PROFILES & FARM CHARACTERISTICS

1.0	**Gender**	*Male*	*Female*			
2.0	**Age (years)**………………………......					
3.0	**Highest level of education**……………………………………………………….					
4.0	**Household size**	*Total………*	*Below 16 years………*			
5.0	**Marital status**	*Single*	*Married*	*Separated*	*Divorced*	*Widowed*
6.0	**Religion**	*Christianity*	*Muslim*	*Traditional*	*Other………………………*	
7.0	**Employment status**	*Full-time farmer*	*Part-time farmer*	*Pensioner*	*Other……………..*	
8.0	**What is your farm size (ha)?** *Total........................ grazing…………………….*					
9.0	**Land ownership**	*Private/own land*	*Communal/Tribal*	*Leased*	*Borrowed*	
10.0	**How did you acquire the land?**..					
11.0	**Do you have formal training in livestock farming?**	*Yes*	*No*			
12.0	**If yes, specify the training**…………………………………………………………….					
13.0	**How many years do you have farming with livestock? (years)**……………					
14.0	**Of the following, what are your sources of income?**					
	Source **Tick**	**Rank** *(1 being the highest source)*				
	Crops					
	Livestock					
	Salary/wages					
	Other (specify)					

15.0	**What livestock species do you farm with?** *(rank with 1 being the most important species)*					
15.1	**Class**	*Cattle*	*Goats*	*Sheep*	*Chickens*	*Other………..*
15.2	**Rank**					
15.3	**Number of animals**					
16.0	**What cattle breeds are you keeping?**	*Nguni*	*Brahman*	*Mixed*	*Other…………………*	
16.1	**Which one is the most important breed?**					
17.0	**What is the general body condition of your cattle?**	*Very poor*	*Poor*	*Fair*	*Good*	*Very Good*
18.0	**What is the average number of calves do you get per production season/ Year?**..................................					
19.0	**How many calves did you wean between November 2019 and November 2020?**..................................					
20.0	**At what age do you wean your calves?**.........................					
21.0	**How many lactating cows do you have**?...............................					
22.0	**On average, what is the calving interval of your cows?**	*12months*	*18 months*	*24 months*		
23.0	**How did you acquire your cattle herd?**..................…………………………………………………..					
24.0	**If you acquired your cattle as a loan, how many animals have you repaid so far?** ………………..					

B. ACCESS TO AGRICULTURAL EXTENSION & VETERINARY SERVICES

25.0	**Do you have access to agricultural extension services?**	*Yes*	*No*

25.1	**If Yes to Q25: Who provides the agricultural extension services?** ……………………………………………………………………………………………………… ………………………………………………………………………………………………………..					
25.2	**If Yes to Q25: What kind of agricultural extension services do you get?** ………………………………………………………………………………………………… ………………………………………………………………………………………………… ………………………………………………………………………………………………….					
25.3	**If Yes to Q25: How do you access the agricultural extension services?** …………………………………………………………………………………………………. ………………………………………………………………………………………………….					
26.0	**What is the quality of the extension services?**	*Very poor*	*Poor*	*Fair*	*Good*	*Very good*
27.0	**How many times do you meet a government an extension officer per year?** …………………					
28.0	**What challenges do you face in accessing extension services?** 1…………………………………………………2………………………………………………………… 3…………………………………………………4……………………………………………………….					
29.0	**Do you have access to veterinary services?**	*Yes*	*No*			
	Who provides the Veterinary services……………………………………………………………………..					
29.1	**If Yes to Q29: What kind of veterinary services do you get?** ………………………………………………………………………………………………… ………………………………………………………………………………………………… ………………………………………………………………………………………………….					
29.2	**If Yes to Q29: How do you access the veterinary services?** …………………………………………………………………………………………………. ………………………………………………………………………………………………….					
30.0	**What is the quality of the veterinary services?**	*Very poor*	*Poor*	*Fair*	*Good*	*Very good*
31.0	**How often to do meet a veterinarian per year?** ……………………………………………					
32.0	**What challenges do you face in accessing veterinary services?** 1…………………………………………………2………………………………………………………… 3…………………………………………………4……………………………………………………….					

C. ICT-BASED STRATEGIES IN SMALLHOLDER LIVESTOCK FARMING

33.0	**Do you own a mobile phone(s)?**	*Yes*	*No*			
33.1	**If yes to Q33: what is the type of your phone(s)?**	*1……………………….*	*2……………………….*			
34.0	**Which mobile network(s) do you subscribe to?** *(Rank with 1 being the most used network)*					
	Network provider	*Vodacom*	*MTN*	*Cell C*	*Telkom mobile*	*Other*
35.0	**What is the quality of mobile network services you get?**	*Very poor*	*Poor*	*Good*	*Very good*	
35.1	**If poor to very poor, what challenges are you facing?** *1…………………………………2…………………………………………3……………………*					
36.0	**How much do you subscribe per month** *Airtime R………………?* *Data R……………….*					
37.0	**If you do not have a phone, are you able to acquire a phone?**	*Yes*	*No*	*Maybe*		
38.0	**If No to Q33: Why are you not able to get a phone?** ………………………………………………………………………………………………					
39.0	**Are you able to operate a smartphone?**	*Yes*	*No*			
39.1	**If yes, how do you rate your skills level?**	*Very high*	*High*	*Medium*	*Low*	*Very low*
40.0	**If your skills are low to very low, is there anyone within your household/ at your farm who can assist/train you on how to operate the phone?**	*Yes*	*No*	*Not sure*		
41.0	**What other ICT-based devices do you own?**	*Computer*	*Tablet*	*Other…………………*		
42.0	**Do you sometimes connect to the internet?**	*Yes*	*No*			
42.1	**If Yes to Q42: Which gadget(s) do you usually use to access the internet?** 1…………………………………………………2………………………………………………..					
42.2	**If Yes to Q44: What agricultural-related information/ services do you search on the internet?** *Information*………………………………………………………………………………… *Other services*……………………………………………………………………………………					
43.0	**Are they any ICT-based Apps that you are aware of which are being used to acquire and/or share agricultural information by farmers?**	*Yes*	*No*			

43.1	**If Yes to Q43: What are these ICT-based Apps?** *1*……………………………………………………………*2*…………………………………………………… *3*……………………………………………………………*4*……………………………………………………		
43.2	**If Yes to Q43: Do you use any of the above ICT-based Apps?**	*Yes*	*No*
43.3	**If Yes to Q43: Which one(s) and what do you use them for?** *1*………………………………………………………………………………………………… *2*…………………………………………………………………………………………………		
44.0	**If there are no ICT-based Apps that you are using, why are you not using Apps?** …………………………………………………………………………………………… ………………………………………………………………………………………………		

D. PERCEPTIONS & OPINIONS TOWARDS THE PROPOSED LMDS [*NB: Read and clearly explain information below about LMDS before asking questions*]

The current study is proposing the use of a mobile phone and web-based application called "LMDS" to improve agricultural extension support towards your livestock farming and assist you in managing and marketing your livestock as well as in communicating with other farmers, extension officers, researchers, buyers and sellers.

	Please indicate the extent to which you agree or disagree with the following statements about the proposed LMDS	*Strongly agree*	*Slightly agree*	*Undecided*	*Slightly disagree*	*Strongly disagree*
45.0	Mobile phone based LMDS is a good system for acquiring appropriate livestock production information					
46.0	The system makes it easier and quicker to access extension services from extension officers					
47.0	The system will allow me to interact directly with extension officers					
48.0	The system will help me save time and costs previously incurred in acquiring information					
49.0	The system will allow me to interact with local researchers					
50.0	Using the system will allow me to access market information in real-time					
51.0	Using the system will create opportunities for accessing better markets					
52.0	It will improve the skills and knowledge between me and other farmers					
53.0	It will enable me to collaborate with other farmers					
54.0	The LMDS is a useful tool for remotely located farmers					
55.0	The system can provide me with weather forecasts and other danger alert SMS in real-time					
56.0	This is a good system for linking with agricultural service providers (Training, financial institutions etc)					
57.0	It is good for record keeping					
58.0	It will enable farmers to report stock theft and locating stray animals					
59.0	The system will be useful during periods like the COVID-19 pandemic					
60.0	The system will be difficult to use because it requires technical literacy, which I do not have					
61.0	Mobile phone handsets are costly to acquire and maintain, hence I will not access the system					
62.0	I will not be able to use it because mobile data is expensive					
63.0	**Will you be willing to pay a yearly subscription fee for you to continue accessing services from the LMDS?**			*Yes*	*No*	*Not sure*
63.1	**If No to Q63: Given that the government pays 50% of the subscription fee, are you willing to pay the remaining 50%?**			*Yes*	*No*	*Not sure*
63.2	**If No to Q63: Given the government fully pays for the subscription fee, are you willing to accept the LMDS program?**			*Yes*	*No*	*Not sure*
64.0	**What do you perceive as challenges/barriers that may affect how you are going to use the LMDS?** *1……………………………………………………………………………2……………………………………………………………………………* *3……………………………………………………………………………4……………………………………………………………………………* *5……………………………………………………………………………6……………………………………………………………………………*					

E. THE SUTAINABILITY OF SMALLHOLDER LIVESTOCK PRODUCTION

ECOLOGICAL CONDITIONS

65.0	**How do you describe the condition of rangelands/natural pastures on your farm?**	*Very poor*	*Poor*	*Fair*	*Good*	*Very good*

66.0	**If your rangelands are poor to very poor, what is causing that?**					
Plant biodiversity loss	*Presence of invasive species*	*Lack of grazing camps*	*Soil erosion*	*Overgrazing*	*Dry conditions*	*Other ……………………….*

67.0	**What is the main grazing system that you practice at your farm?**			
Rotational grazing	*Continuous grazing*	*Zero grazing*	*Short duration grazing*	*No standard grazing system*

NB: Clearly explain this to the farmer: *Under your production system rangelands are the most important input in your cattle farming business. However, when the cattle graze in the rangelands, the forage is depleted. Normally, the forage regenerates naturally, but if this natural regeneration rate is less than the rate of depletion from grazing, the rangelands degrade, thus making your farming enterprise less sustainable. Therefore, to ensure productivity of cattle, every year there must be efforts to bring back the rangelands to their original state. One method to achieve this is through annual subscriptions to cover the costs of regenerating the rangelands (cost of the ecosystem services for grazing). Estimates show that it may require about R165 for the regeneration of 1 ha.*

68.0	**Are you willing to pay an amount of R165 per Ha/per year for the regeneration of your rangelands?**			
	Yes		*No*	
68.1	**If Yes to R165, how about if the amount is increased to R250**		**If No to R165, how about if the amount is reduced to R85**	
	Yes	*No*	*No*	*Yes*
68.2	**If Yes to R250, how about if the amount is increased to R330**		**If No to R85, if the government pays the full amount for you, are you willing to accept the programme of regenerating your rangelands?**	
	Yes	*No*	*No*	*Yes*

69.0	**Are you carrying out any rangelands regenerating practices at your farm?**	*Yes*	*No*
69.1	**If Yes, what are some of the strategies that you are using to regenerate your rangelands?** ………………………………………………………………………………………………. ……………………………………………………………………………………………….		

70.0	**Besides rangelands, what other feed sources do you use to feed your livestock?**		
Planted pastures	*Agricultural by-products*	*Bought-in feeds*	*Others (specify)* ……………………

71.0	**How do you describe the accessibility of the other feed source/s you mentioned above?**			
Very poor	*Poor*	*Fair*	*Good*	*Very good*

72.0	**What is the main source of water for your cattle?**..			
73.0	**How do you describe the availability of water resource at your farm?**			
Very poor	*Poor*	*Fair*	*Good*	*Very good*

74.0	**How do you describe cattle breeding management practices at your farm?**			
Very poor	*Poor*	*Fair*	*Good*	*Very good*
74.1	**If poor to very poor, what main breeding challenges do you face?** ……………………………………………………………………………………………… …………………………………………………………………………………………………..			

75.0	**How do you describe the level of climate change impact on your farm?**			
Very high	*High*	*Low*	*Very low*	*No Impact*

76.0	**How do you describe the level of drought impact on your farm?**			
Very high	*High*	*Low*	*Very low*	*No Impact*

77.0	**How do you describe the level of land degradation on your farm?**			
Very high	*High*	*Low*	*Very low*	*No degradation*

78.0	**How do you describe the occurrence of animal diseases at your farm?**			
Very high	*High*	*Low*	*Very low*	*No occurrence*

79.0	**How do you describe the challenge of animal parasites at your farm?**			
Very high	*High*	*Low*	*Very Low*	*No parasites*

ECONOMIC CONDITIONS

80.0	**How do you describe accessibility to financial support for your cattle farming business?**			
Very poor	*Poor*	*Fair*	*Good*	*Very good*
81.0	**Where did you get capital to invest in your cattle business?**			
Bank	*State aid*	*Family*	*Own savings*	*Other*…………………………….
82.0	**What total average costs did you incur between November 2019 and November 2020?** R…………			

83.0	**How do you describe the level of your total costs?**	*Very high*	*high*	*Low*	*Very low*
84.0	**Describe the profitability of your cattle farming business in the past 5 years?**	*Highly profitable*	*Profitable*	*Break-even*	*Unprofitable*	*Highly unprofitable*

85.0	**How do you describe accessibility to markets?**			
Very poor	*Poor*	*Fair*	*Good*	*Very good*
86.0	**If poor to very poor, what marketing challenges do you face?** ………………………………………………………………………………………………….. …………………………………………………………………………………………………. ………………………………………………………………………………………………			
87.0	**Cattle sold between November 2019 to November 2020?**			

Month	*Number sold*	***Sold as**:1=Live 2=Slaughtered*	*Price per animal/kg*	*Average age of animal*	*Where sold*	*Distance to market*

88.0	**How do you describe the current market prices for cattle?**				
Very low	*Low*	*Fair*	*Good*	*Very Good*	
89.0	**Did you sell any cattle hides between November 2019 to November 2020?**			*Yes*	*No*

89.1	**If yes to Q89,**			
Month	*Number sold*	*Price received*	*Where sold*	*Distance to market*
89.2	**If No to Q89, what are the reasons for not selling your cattle hides?** ………			
90.0	**What are your main sources of marketing information?** 1……………………………………………………2……………………………………………………			
90.1	**How do you describe accessibility to market information?**			

Very poor	*Poor*	*Neutral*	*Good*	*Very Good*

SOCIAL CONDITIONS

91.0	**How do you describe the contribution of your cattle farming towards household income?**			
Very high	*High*	*Low*	*Very Low*	*No contribution*

92.0	**How do you describe the contribution of your cattle farming towards household food security?**			
Very high	*High*	*Low*	*Very Low*	*No contribution*

93.0	**How do you describe the contribution of your cattle farming towards family's education?**			
Very high	*High*	*Low*	*Very Low*	*No contribution*

94.0	**How do you describe the contribution of your cattle farming towards family healthcare?**			
Very high	*High*	*Low*	*Very Low*	*No contribution*

95.0	**How do you describe the contribution of your cattle farming towards community development?**			
Very high	*High*	*Low*	*Very Low*	*No contribution*

96.0	**How do you describe the level of stock theft in your area?**			
Very high	*High*	*Low*	*Very Low*	*No stock theft*
97.0	**How many animals have you lost in the past year? Due to:**			
Stock theft………..	*Straying…………………..*	*Disease/parasites………………..*	*Predation……………..*	

98.0	**Are you a member of any farmer organisation?**	*Yes*	*No*
98.1	**If yes to Q98, name the organisation (s)** 1…………………………………2…………………………………3…………………………………		
99.0	**What are the benefits of being a member of the group or organisation?** ……………………………………………………………………………………………… ………………………………………………………………………………………………..		
100.0	**If no to Q98, why are you not a member of any farmer group or organisation?** ……………………………………………………………………………………………… ………………………………………………………………………………………………..		
101.0	**Do you participate in sharing information and skills with other farmers?**	*Yes*	*No*
101.1	**If yes, how do you share the information and skills with other farmers?** ……………………………………………………………………………………………… ………………………………………………………………………………………………		
102.0	**Currently, what is the source of labour for your cattle farming activities?**		

Source	*Full-time employed labour*	*Part-time hired labour*	*Family labour*	*Other……………………..*
Number				

Thank you for your time!!

Appendix 2: Focus Group Discussion Guide

FOCUS GROUP DISCUSSION GUIDE: NW NGUNI CATTLE FARMERS

Stellenbosch University, Faculty of AgriSciences

*Hello my name is **Xoliswa Mphahla**. We are interested in finding out about your experiences and perceptions regarding the use of ICTs including the internet, mobile phones and computers to support your livestock production system. Data collected will be used in a PhD study on the "Development of a Livestock Management Database System (LMDS)" for improving the sustainability of your livestock production systems being conducted by Mr. O. Mapiye (a PhD student from SU).*
The LMDS will be a mobile phone-based application system that will be accessed using smart phones and computers. The system will help you access relevant, accurate and timely agricultural information, inputs and services which you need to effectively manage and grow your farm business. Through the system you can access reliable market information and better market opportunities which allow you to sell at better market prices and have improved farm cashflows, and higher profits. It improves your ability to directly share relevant challenges, skills and experiences with fellow farmers and also to directly communicate with extension officers and local researchers leading to better farm management and growth. The LMDS system is a tool which you can use to record and keep all your farm activities which helps you make better management decisions.
*The FGD will take no more than 1hr 30 minutes. We would like to record the discussion so that we will be able to remember what was said, as we cannot take notes on everything. No one will have access to the recordings except the research team. The recordings will be kept safely until they are transcribed word for word, then they will be destroyed. **NB:** Please read and briefly discuss the consent form and ask participants if they understood and willing to continue with the discussion!*

Refreshing some ground rules

- *The most important rule is that only one person speaks at a time. I understand there will a temptation to jump in when someone is still talking but please wait until he/she is finished.*
- *There are no right or wrong answers*
- *You do not have to speak in any order*
- *You do not have to wait for anyone to speak before you speak. This is an open discussion.*
- *You do not necessarily have to agree with the views of other group members*

Warm up
Firstly, I would like everyone to briefly introduce themselves. Ok, let us begin!

Guiding questions

1. **Firstly, we would like to understand your experiences with the current agricultural extension system.**

a) Who is providing the extension services and what kind of services are they giving you?

b) What methods are being used to provide the services?

c) What are the most critical challenges you face in accessing extension services?

2. **Now we would like to understand your experiences with the current veterinary support services**

a) Who is providing the veterinary services and what kind of services are they giving you?

b) What methods are being used to provide the services?

c) What are the most critical challenges you face in accessing veterinary services?

3. **Can you share your general experiences or knowledge on the use of ICTs preferably internet and mobile phone-based technologies and/Apps to support your livestock farming business?**

a) Identify the technologies and/Apps and what you are using them for.

b) What is your experience with them?

d) How did you find out about them?

e) Do you know other people who know about and use ICTs for their livestock management? What do they say about them?

4. **Now we need to understand your perceptions and opinions about the proposed Livestock Management Database System**

After development and availing of the LMDS platform, it is important for it to continue providing you all these services and support your farm business. The system must, therefore, be constantly maintained and upgraded to provide more services, and this will come at cost.

a) How do you perceive the usefulness of this system towards your cattle farming and why?

b) How much subscription fee do you think a commercially oriented farmer like you should pay per year for using the system?

b) What barriers/challenges might affect adoption and usefulness of the LMDS and what recommendations do you give to reduce the problems?

5. **Comment on the sustainability and/performance of your cattle farming project.**

a) What challenges other challenges you are facing, especially as you expect to grow your herd size?

This is the end of our interview, any questions?

Concluding remarks
Thank you all for participating in FGD. This has been a very successful discussion and your opinions will be a valuable to the study and hope you have found the discussion interesting as well.
Before you leave, let me collect your completed personal details questionnaire slips

Appendix 3: Key Informant interview Guide

<u>KEY INFORMANT INTERVIEW GUIDE:</u> NW PROVINCE AGRICULTURAL ECTENSION ADVISORS

Stellenbosch University, Faculty of AgriSciences

Dear participant my name is Obvious Mapiye I am conducting research on the "Development of a Livestock Management Database System (LMDS)" for sustainable livestock production in the smallholder sector, South Africa. An LMDS will be a web-based platform or mobile phone-based application that will be accessed using mobile phones and computers. Besides allowing the farmers to share their experiences and skills among themselves, the LMDS promotes frequent two-way communication between farmers, extension officers and local researchers. Strengthening the Farmer-Extension-Research Linkage helps in generating appropriate, timely and relevant solutions for the farmers. Furthermore, the LMDS is expected to increase the extension practitioner to farmer ratio which means more farmers can be serviced per extension officer. It will also assist the department in developing a database of smallholder livestock farms and farmer activities in the province.
We are interested in finding out about your perceptions, opinions and recommendations regarding the development and use of ICTs such as the proposed LMDS in improving the province's agricultural extension system and growth of smallholder livestock farmers.

PARTICIPANT INFORMATION	
Date of interview:	Sex of respondent:
Province:	Age:
Place of interview:	Specialty:
Education Level:	Number of years in service:
Number of farmers covered:	Name of Interviewer

<u>Guiding questions</u>

1. Can you briefly share your experiences with the current extension system?

a) What services are you giving to the farmers and how are you delivering the services?
b) What are the most critical challenges that you are facing in delivering extension services?

2.Can you share your general experiences or knowledge on the use of ICTs preferably mobile phone-based technologies in agricultural extension. ***Please identify the strategies and what they are being used for by:***

a) Smallholder Farmers
b) Extension officers

3.What impact do you think an innovation like the <u>Livestock Management Database System</u> will have? On:

a) Sustainability of smallholder livestock farmers?
b) Delivery of extension services by the Department of Agriculture?

4. After development and availing of the "Livestock Management Database System" what are the chances that it will be accepted by the farmers and extension officers?

5. What do you perceive as the barriers/challenges to the adoption and implementation of the LMDS?

a) Farmers
b) Extension officer

7. Sustainability of the Nguni projects in your district

Rangelands are the most important production input under smallholder production systems. However, when the cattle graze in the rangelands, the forage is depleted. Normally, the forage regenerates naturally, but if this natural regeneration rate is less than the rate of depletion from grazing, the rangelands degrade, thus making your farming enterprise less sustainable. Therefore, to ensure productivity of cattle, every year there must be efforts by the farmers to bring back the rangelands to their original state. One method to achieve this is through annual subscriptions to cover the costs of regenerating the rangelands (cost of the ecosystem services for grazing). Estimates show that it may require about R165 for the regeneration of 1 ha.

a) Comment on the possibility of farmers agreeing to pay such an amount to be used in generating their rangelands
b) Comment on the performance of Nguni farmers in your district (Herd sizes, loan repayment, farm investment, recruitment of new beneficiaries)
c) What marketing challenges are affecting the Nguni cattle farmers in your district?
d) Besides the marketing challenges what other limitations are affecting sustainability of the Nguni farmers

This is the end of our interview, any questions?

Appendix 4: User Point of View Statement Template

<table>
<tr><th>User</th><th>Needs</th><th>Insights</th></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">User [identified targeted user] needs [deep user need] so that they may [ideal motivation for solving their problem]</td></tr>
</table>

Appendix 5: Components and respective questions used in creating the LMDS Business Model Canvas.

Strategyzer

Business Model Canvas

Key Partnerships

- What are the key partners that are needed to leverage the tool and its business model?

Key Activities

- What key activities do the value propositions require?

Key Resources

- What key resources do the value propositions requires?

Value Propositions

- What needs are going to be satisfied?
- What is the tool offering the customer segments?

Customer Relationships

- How are the customers segments going to be reached and convinced about the value being offered?

Channels

- How are the customers segments going to be reached?

Customer Segments

- Who are the most important customers?

Cost Structure

- What are the most important costs?

Revenue Streams

- What are the customers going to pay?