International Journal of Technoscience and Development (IJTD)

Vol 4, 2019 Issue, ISSN 2001-2837

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Homogeneous Transparent Conductive Al-doped ZnO Thin Films Deposited by Reactive Direct Current Magnetron Sputtering

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ABSTRACT

Reactive direct current sputtering of Al-doped ZnO films faces a serious drawback of lateral heterogeneity of the electrical properties of the films due to bombardment of the film by negative oxygen ions. By adopting appropriately large target-substrate distance and tuning the oxygen flow rate, Al-doped ZnO (AZO) films were reactively sputtered on a glass substrate from $Zn_{0.98}$ $Al_{0.02}$ alloyed target. The properties of the films were investigated as a function of the position of the substrate with respect to the magnetron axis, using X-ray diffractometer, UV-Vis-NIR spectrophotometer and four-point probe. Results indicated that, both resistivity and optical transmittance were homogeneous across the substrate positions, irrespective of the oxygen gas flow rate (OFR); due to reduced bombardment by negative oxygen ions and uniformity in the film composition, respectively. There was a transition in the film properties from absorbent and highly conducting to transparent and more resistive, with the increase of the OFR from 3.5 to 6 sccm, which is related to a transition from sub-to-over stoichiometry. With an optimum OFR of 4 sccm, transparent AZO films with a homogeneous minimum resistivity of the order 10^{-3} Ω cm were obtained across the substrate positions. The film thickness was quite homogeneous, with values between 182 and 218 nm. The optimized films also crystalized in a homogeneous wurtzite structure and (002) preferred orientation along the c-axis. But crystallinity and optical band gap were heterogeneous. The former improved monotonically with increase in substrate position due to relaxation of stress at higher substrate positions, while the latter increased steadily with the increase in the substrate positions due to Burstein-Moss effect. Therefore, the experimental results showed that by adopting appropriately large target-substrate distance and tuning the oxygen gas flow rate, homogeneous transparent conductive AZO films was deposited by reactive direct current sputtering on a glass substrate from $Zn_{0.98}Al_{0.02}$ alloyed target.

Keywords: AZO films, Homogeneous resistivity, Reactive d.c magnetron sputtering, substrate position, Transparent conducting oxide.

1.0 INTRODUCTION

Transparent conducting Al-doped ZnO (AZO) thin films are potential candidates for application as transparent electrode in photovoltaics and flat panel displays (Mickan *et al.*, 2016). For these applications a low resistivity of the AZO films of the order of 10^{-3} -10^{-4} Ω cm is required (Gupta *et al.*, 2013; Kumar and Rao, 2012). In practical device production large area substrates are often used and lateral homogeneity of the electrical and optical properties of the film is crucial (Horwat *et al*., 2010). A common technique to deposit AZO films is reactive direct current (DC) magnetron sputtering because of its scalability to large area substrates, up to 20 m^2 (Abduev *et al*., 2007; Cornelius *et al*., 2009; Ginley, 2011). Nevertheless, the reactive sputtering technique has a serious drawback of heterogeneity of the electrical properties (Ou *et al.*, 2016). The resistivity of the deposited AZO films is reported to increase by several orders of magnitude in front of the magnetron or target (Ellmer and Welzel, 2012; Horwat and Billard, 2007; Mickan *et al*., 2016). This has been related to bombardment of the film surface with negative oxygen ions originating from the target, which is high in front of the magnetron. The bombardment introduces point defects such as Zn vacancies and O_2 interstitials that can compensate the donors (Bikowski *et al*., 2013; Janotti and Walle, 2009). To circumvent the problem, Jullien et al. (2011) proposed fine-tuning oxygen gas flow rate to achieve a good compromise between optical transparency and electrical homogeneity of AZO films. Furthermore, Horwat and Billard (2007) reported significant reduction in the heterogeneity of conductivity of AZO films with increase of target-substrate distance from 6 to 10 cm.

In this study a large target-substrate distance of 11 cm and tuning of the oxygen gas flow rate are adopted in the deposition of AZO films. Electrical, optical and structural properties of the films have been investigated as a function of the sample position relative to the magnetron axis, in order to evaluate the homogeneity of the properties.

2.0 MATERIALS AND METHODS

Thin films of AZO were deposited on unheated glass substrates by sputtering from an alloyed $Zn_{0.98}Al_{0.02}$ target in the presence of argon-oxygen reactive gas mixture. A schematic drawing of the sputtering chamber is shown in figure 1. The target had a diameter of 5 cm and was fixed on a magnetron powered by direct current (DC) supply. The substrate was fixed on a rotating substrate holder using a polyimide tape and parallel to the target surface. There were nine sample positions on the substrate surface at various lateral distances from the magnetron axis (0-8 cm) as indicated in figure 1. The vertical distance between the target and the substrate was fixed at 11 cm. The sputtering chamber was pumped down via a rotary vane pump and a turbo-molecular pump allowing a base pressure of 10^{-3} Pa.

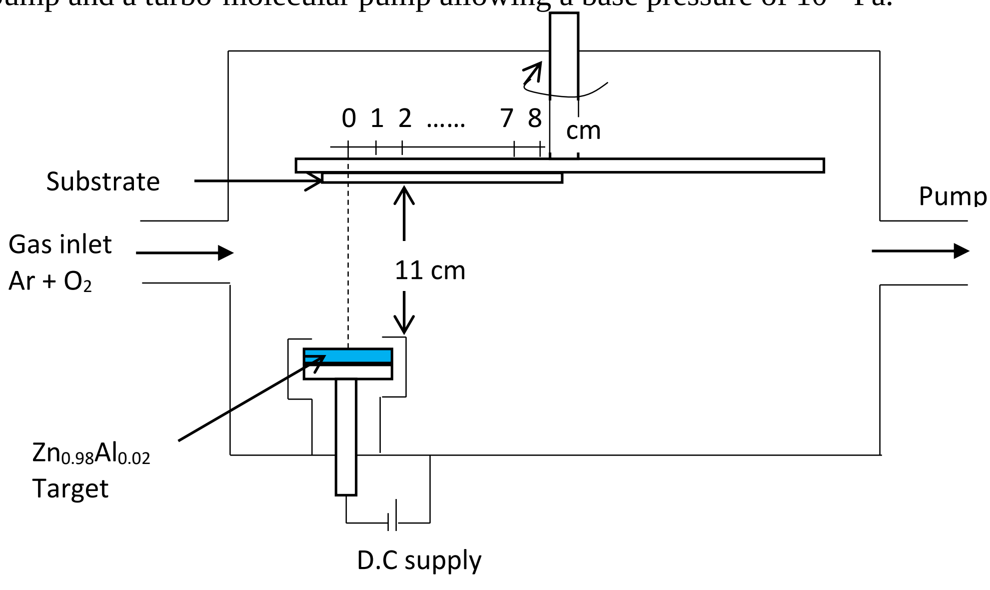

Figure 1: Schematic representation of the sputtering chamber.

The argon gas flow rate was fixed at 50 standard cubic centimeters per minute (sccm) and the oxygen flow rate (OFR) was varied in the range 3 -7 sccm giving a final working pressure of about 0.6 Pa. The surface of the substrate was cleaned by plasma etching using radiofrequency (60W, 2 minutes) in the reactive ambiance before deposition. The discharge current was fixed at 0.12 A and deposited time was 60 minutes. The optical transmittance of the AZO films was measured in the ultraviolet and visible range using a Cary 5000 UV-Vis-NIR spectrometer. The sheet resistance and resistivity were measured using a 4-point probe setup. Film thickness was determined with alpha-step IQ surface profiler and the structural properties were measured using $\theta/2\theta$ X-ray diffraction (XRD) with an AXS Bruker D8 Advance diffractometer with a Cu anode (Cu K_α = 0.154 nm).

3.0 RESULTS AND DISCUSSION

3.1 Electrical and Optical Properties

All the AZO films exhibited *n*-type conductivity. Figure 2 shows the dependence of electrical resistivity on both oxygen gas flow rate (OFR) and substrate position.

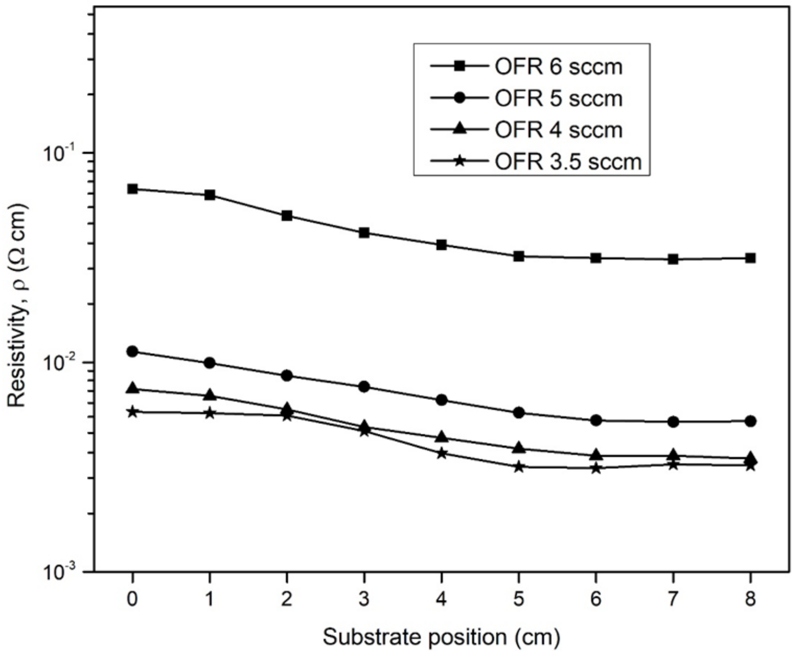

Figure 2: Resistivity of AZO films for different oxygen gas flow rates (OFR).

No matter the OFR, film resistivity is homogeneous in the order of magnitude across the substrate positions but a slight increase in size towards the magnetron axis can be observed. The order of magnitude is 10^{-3} Ω cm for OFR 3.5, 4 and 5 sccm and 10^{-2} Ω cm for OFR 6 sccm. The homogeneous order of magnitude suggested less bombardment of the AZO film surface in front of the magnetron by negative oxygen ions (Ellmer and Welzel, 2012). Furthermore, there is a transition in the film resistivity from low to high with increase of OFR from 3.5 to 6 sccm, across all the substrate positions. The transition is ascribed to chemisorption of excess oxygen on the film surface at higher OFR which gets bonded at the defects causing an increase in resistivity (Sundaram and Khan, 1997). Additionally, increase in OFR causes a transition from sub-to over stoichiometry of the AZO films leading to transparent but more electrically resistive films (Chamorro *et al.*, 2013; Ginley, 2011; Horwat and Billard, 2007). Figure 3 (a-d) confirms a transition from dark to transparent films with increase of the OFR from 3.5 to 6 sccm. The average visible transmittance (wavelength 380-780 nm) across the substrate positions is in the range 68-70, 82-83, 85-87 and 89-90 % for OFRs 3.5, 4, 5 and 6 sccm, respectively.

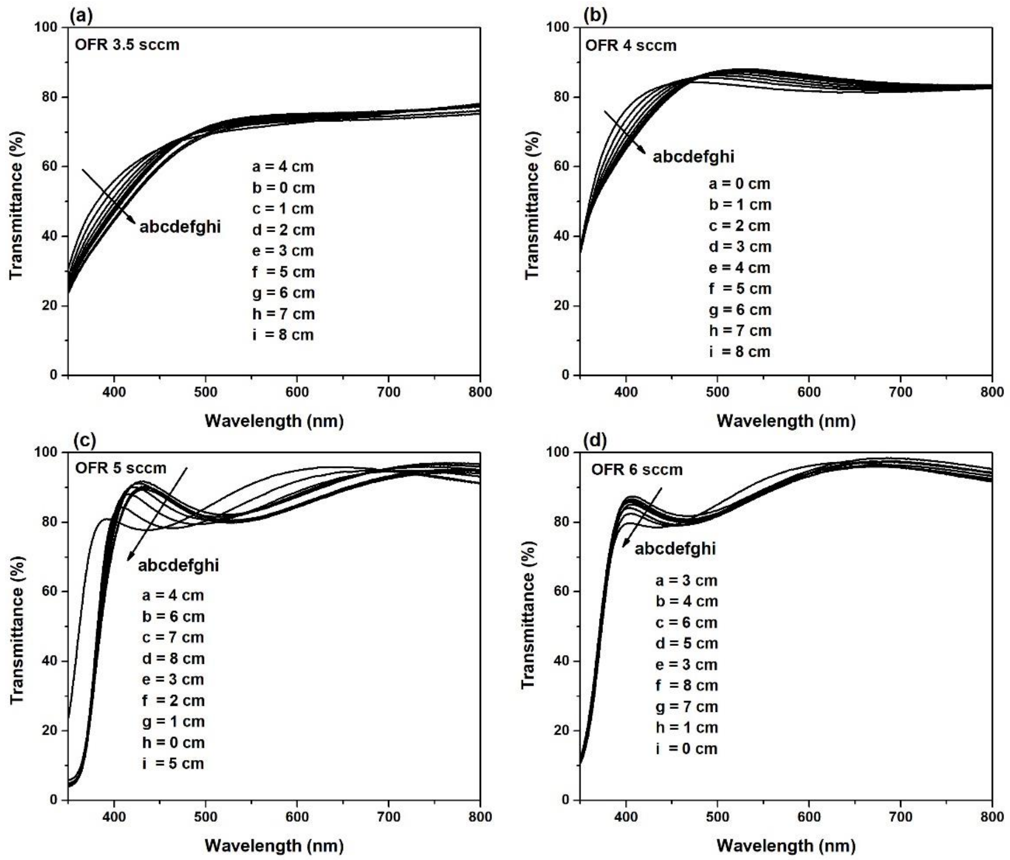

Figure 3: Variation of transmittance of AZO films with substrate positions for different oxygen flow rates (a) OFR 3.5 (b) OFR 4 (c) OFR 5 and (d) OFR 6 sccm.

Comparing resistivity and transmittance results of figures 2 and 3, respectively shows that OFR 4 sccm represents the best compromise between good transmittance and low resistivity of films. Thus, optimized AZO films are obtained with OFR 4 sccm as the optimum. From figure 2, it can be observed that the optimized AZO films exhibited maximum resistivity of 7.45×10^{-3} **Ω** cm at the magnetron axis which steadily decreased to a minimum of 3.47×10^{-3} **Ω** cm off the axis, with the same order of magnitude. The trend relates to the improvement in crystallinity shown by small values of FWHM in figure 5 (b) and the increase in charge carrier concentration indicated by widening of optical band gap shown in figure 4. It is known that higher crystallinity lowers the resistivity of Al-doped ZnO films (Barreau and Kessler, 2008), while widening of the optical band gap is linked to an increase in the carrier concentration based on Burstein-Moss effect (Mickan *et al*., 2016; Sernelius *et al*., 1988).

The observed transparency of the AZO films at different OFR is also linked to the size of the optical bad gap of the films (Kumar and Rao, 2012). The band gap of the optimized AZO films (obtained with the optimum OFR of 4 sccm) have been investigated. Tauc's method was used to determine the band gap values in the UV and visible region using the transmittance data (Tauc, Grigorovici and Vancu, 1966). The absorption coefficient α and the band gap E_g are related according to equation 1.

$$\alpha h v = A\left(h v - E_g\right)^{1/2} \quad (1)$$

where A is a constant, hv is the photon energy and α is calculated using Lambert's laws using equation 2 (Kumar et al., 2013).

$$\alpha = \frac{1}{t} ln\left(\frac{1}{T}\right) \quad (2)$$

where T is the transmittance and t is thickness of the film

The inset graph in figure 4 shows Tauc's plot of $(\alpha h\nu)^2$ versus $h\nu$ from which band gap values were determined. The linearity of the plots confirmed the direct band gap of AZO films. Figure 4 shows evolution of the band gap with substrate position. It steadily increased from a minimum of 3.396 eV at the magnetron-axis to a high of 3.483 eV at the farthest substrate position of 8 cm. The band gap values are within the reported range of 3.25 – 3.55 eV for Al-doped ZnO films (Horwat and Billard, 2007). The evolution is related to Burstein-Moss effect that links an increase of the band gap to an increase in the charge carrier concentration (Mickan *et al.*, 2016; Kumar and Rao, 2012; Sernelius *et al.*, 1988).

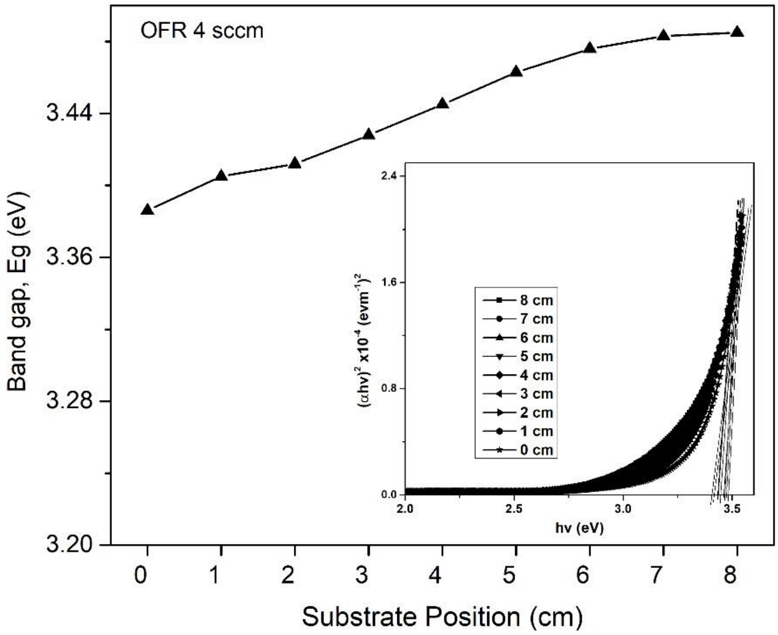

Figure 4: Evolution of band gap with substrate position for optimized AZO films obtained with the optimum OFR of 4 sccm. Inset is Tauc's plot of $(\alpha h\nu)^2$ versus hν used to determine the band gap.

3.2 Structural Properties

The structural properties were examined for the optimized AZO films obtained with the optimum OFR of 4 sccm. Figure 5 (a) shows the X-ray diffraction (XRD) spectra of AZO films as a function of substrate position. All the films consistently exhibited a dominant (002) peak and weak (100), (101), (110), (103) peaks that are characteristic of planes of ZnO wurtzite structure (Wu *et al.*, 2014). The result indicated formation of wurtzite structure with preferred c-axis orientation normal to the substrate position for all substrate positions. The absence of impurity phases or compounds of Zn and Al detected showed all films were highly polycrystalline (Baek *et al.*, 2012).

Figure 5 (b) shows variation of full width at half maximum (FWHM) and 2θ of the (002) peak and film thickness with substrate position. FWHM decreased monotonically with increase of the substrate position, indicating improvement of crystallinity at higher substrate positions. This can be attributed to relaxation of film stress with increase of the substrate position, as indicated by a shift in 2θ towards the standard value of 34.45^{o} for stress free bulk ZnO, as shown in figure 5 (b) (Ali *et al.*, 2013) . The stress originates from both the mismatch in the ionic radii of Al^{3+} (0.054 nm) and Zn^{2+} (0.074 nm) in the ZnO lattice and the difference in the thermal expansion coefficients of AZO film and the glass substrate (Kumar and Rao, 2011; Muchuweni *et al.*, 2017; Park, 2014). The film thickness exhibited a minimal variation with substrate position, fluctuating within the range 182-218 nm. The nearly homogeneous thickness is attributed to rotation of the substrate during sputtering. (Horwat and Billard, 2007).

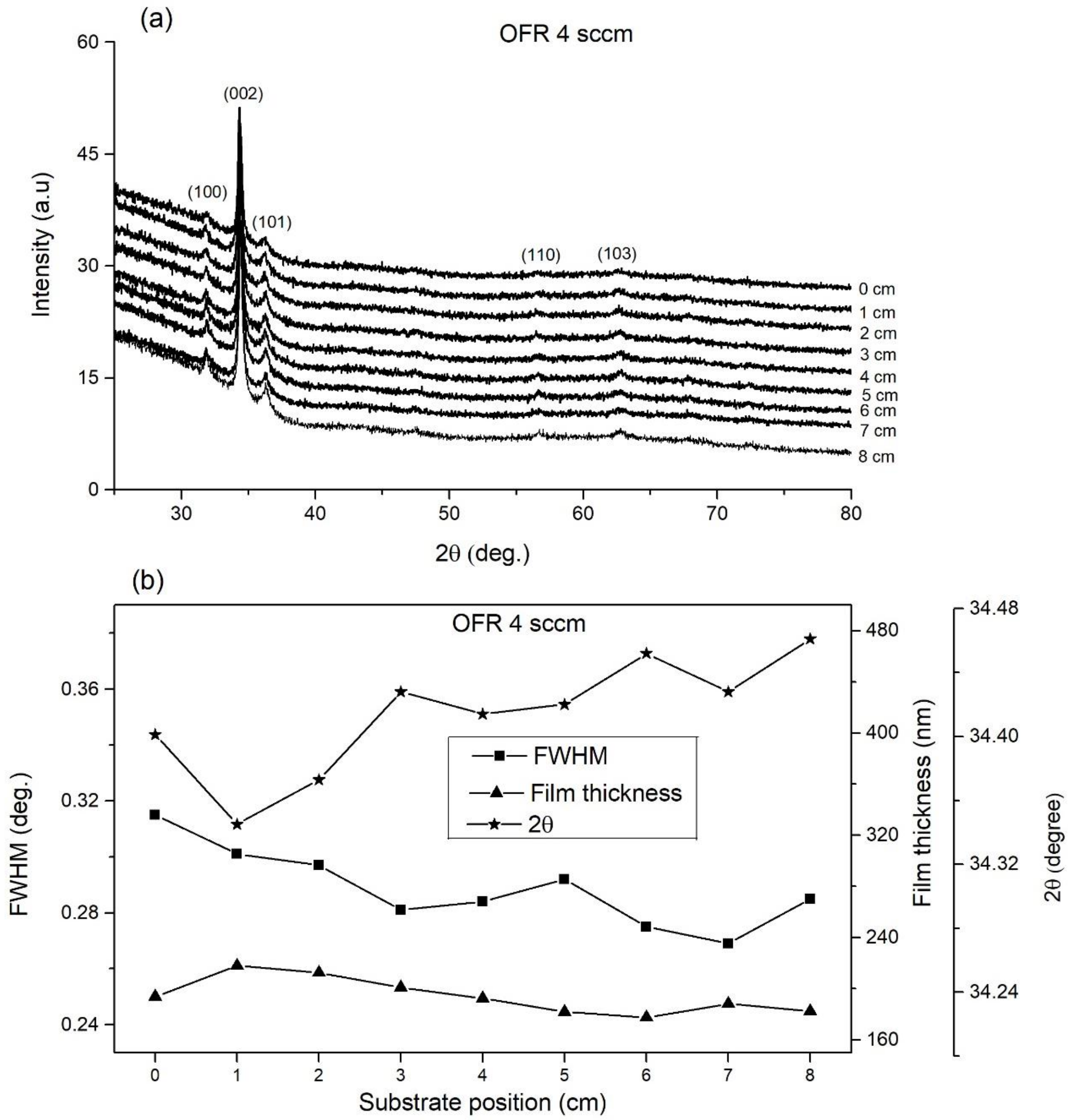

Figure 5: (a) X-ray diffraction spectra (b) FWHM, 2θ (of the (002) peak) and film thickness of AZO films as a function of substrate position for the optimum OFR of 4 sccm.

4.0 CONCLUSION

AZO films were prepared by reactive DC magnetron sputtering on a glass substrate using $Zn_{0.98}$ $Al_{0.02}$ alloyed target and investigated for lateral homogeneity of electrical, optical and structural properties over nine sample positions on the substrate surface located at different lateral distances from the magnetron axis (0-8 cm). The investigation adopted a large target-substrate distance of 11 cm and optimized oxygen gas flow rate (OFR) to obtain transparent conductive AZO films with minimum resistivity. The results showed that, regardless of the OFR, there was lateral homogeneity of both resistivity (in the order of magnitude) and optical transmittance due to reduced bombardment of the film surface in front of the magnetron by negative oxygen ions and uniformity in the film composition, respectively. With an optimum OFR of 4 sccm, transparent conductive AZO films with minimum resistivity in the order of magnitude 10^{-3} Ω cm were obtained for both on axis and off axis substrate positions.

Although there was a slight increase in size towards the magnetron axis at most by a factor of 2, from a minimum of 3.47 x 10^{-3} Ω cm off the axis to a maximum of 7.45 x 10^{-3} Ω cm at the axis. The film thickness was quite homogeneous, with values between 182 and 218 nm, attributed to rotation of the substrate during deposition. The optimized films also crystalized in a homogeneous wurtzite structure with preferred (002) orientation along the c-axis normal to the substrate surface. However, both crystallinity and optical band gap were heterogeneous. The former improved monotonically with increase in substrate position due to relaxation of stress at higher substrate positions, while the latter increased steadily with the increase in the substrate position due to Burstein-Moss effect. The findings showed that by adopting appropriately large target-substrate distance and tuning the oxygen gas flow rate, homogeneous transparent conductive AZO films can be obtained on a glass substrate by reactive DC magnetron sputtering from $Zn_{0.98}Al_{0.02}$ alloyed target.

5.0 ACKNOWLEDGEMENTS

This work was supported by the International Science Programme (ISP), Uppsala University, Sweden and The Africa Center of Excellence in Materials, Product Development and Nanotechnology (MAPRONANO ACE)-Makerere University.

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Biogas digester performance measurement with changing temperature: A facile lab-scale evaluation using cow dung substrate

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ABSTRACT

Biogas remains a relatively eco-friendly alternative energy source to the hazardous fossil fuels. It is produced anaerobically, and mainly composed of methane (CH4) and carbon dioxide (CO2) gases. Anaerobic processes are sensitive to environmental changes in temperature, pH, and C/N ratio besides other operational practices. Temperature regimes determine the well-being and co-existence of various archaeal communities in biogas systems. Moreover, shifts in temperatures have rendered some biogas systems passive due to unfavorable enthalpies for the anaerobes. In Uganda, no attempts have been made to either in-build or manually implement temperature-monitoring capabilities for these systems. This research aimed at finding out the effects that changes in temperature have on biogas systems performance particularly in terms of the amount of biogas output, the methane percentage composition. The effect of temperature was investigated through forced temperature variations imposed on 750 ml Perspex glass bottles loaded with 500 g of substrate. The temperature was varied using a thermostatically controlled water bath. This was done at a retention time of 22 days. The amount of biogas produced per day was measured using the method of downward displacement of water. The methane composition was measured using an Orsat gas analyzer. In this research, it was found that reactor performance in terms of biogas production and percentage composition of methane yields did not vary significantly at the different temperatures. The microorganisms present in these reactors must have a tolerance for a fairly wide range of temperatures. However, drops in biogas production and methane percentage compositions were realized at transition temperatures from mesophillic to thermopillic and reversely too. This could have been due to disruption of bacterial communities that are tolerant to a given temperature range. Where possible, digesters should be kept at thermophillic conditions (40-46 °C) since all peak values for biogas and methane percentage were in this temperature range.

Keywords: *Renewable energy, Anaerobic digestion, Biogas digesters, Temperature*

1.0 INTRODUCTION

1.1 Background

In early 1990's, the government of Uganda through Energy Resources Department, with assistance from IDA funds of the World Bank, started a national biogas pilot project that was not successful either due to poor maintenance and process control (World Bank, 2005). The project employed a World Bank hired technical advisor who was in charge of the project. In 2000, the Government of Uganda through Energy Resources Department implemented a biogas program in and around Kampala (Mccord et al., 2017). Twenty biogas digesters of 8 cubic meters capacity each were constructed in and around Kampala. Two of the biodigesters were built at institutions and the rest at households. All the digesters were functional at the start. Another successful project has been the biogas program undertaken by the Department of Chemistry at Makerere University. This program has constructed 3 demonstration biogas digesters in Mityana District. These projects were generally successful at the start. However, currently very few are still functional.

Private individuals leveraging expertise from local biogas engineers and technicians have made many Initiatives. However, these have not been successful due to reasons ranging from managerial to technical. Limited spread of this technology could be due to some social and economic issues.

1.2 Problem Statement

The global depletion of energy sources and the adverse effects of fossil fuels on the environment pose a challenge to engineers to devise alternative energy source. Among the efforts to combat the problem is the use of renewable energy sources of which biogas systems are part. In Uganda, the spread of this technology is still limited. Most of the biogas systems are no longer functional and those in operation are not performing to the expected outputs. Besides the economic and social factors is the poor control of anaerobic digestion parameters which are the pinnacle for any biogas system performance. Anaerobes are highly sensitive to enthalpy changes and this is one of the causes of gradual and abrupt passivity of biogas systems. The performance of biogas digesters under different temperature regimes has not been studied in Uganda. This study aimed at filling this research gap that could later yield into biogas systems maintenance manuals that are evidence based.

1.3 Study purpose

This batch study aimed at ascertaining the effect temperature has on the chemical reactions involved in each biogas production stage and establish any correlation with the percentage composition of the produced biogas.

1.4 Research question

What is the effect of temperature on performance of biogas digesters in Uganda?

1.5 Scope

This study entails the evaluation of performance of biogas digesters basing on the biogas output and the percentage composition of methane in the gas. It excludes the effect of temperature on the retention time.

1.6 Organization of the article

Section one is an overall introduction of the study including the background, problem statement, purpose of the study and the research question. Section 2 details the methods and materials used in the study. These include the substrate preparations, bio digesters, measuring instruments and the chemical analytics for the biogas quantity and quality. In section 3, the results for both the mesophillic and thermophillic digester performances are presented in both descriptive and graphical formats. A thorough discussion of the results in section 3 is presented in section 4. This gives a comparative analysis of the findings with related literature by past scholars. Conclusions and recommendations are presented in section 5 along with the study limitations and the policy implications of the findings and the drawn conclusions from the study.

2.0 METHODS AND MATERIALS

2.1 Feedstock Preparation

Fresh cow dung was collected from an abattoir near Malangala Sub-County headquarters in Mityana district, Uganda. It was sorted to remove other indigestible materials like stones and metals. It was then kept covered in a heap with polythene bags at ambient temperature for two weeks before the experiment. This was to allow partial digestion before the actual experiment such that less time could be taken to monitor the different temperature shifts. Weighing of the feedstock was done using a digital weighing balance (Mettler PN 163); 500 g of feedstock were loaded in each of the reactors. 250 ml of water was added to the feedstocks. Two thermostatic water heaters (model: NPE-240A) were used to control the temperatures with in the required ranges.

2.2 Equipment

2.2.1 Biodigesters

The reactors used were old acid bottles. These were maintained at a constant desired temperature using hot water circulation around the reactors. Samples were withdrawn from sampling holes (Mixing was achieved by shaking the bottles twice daily in the morning and evening hours.

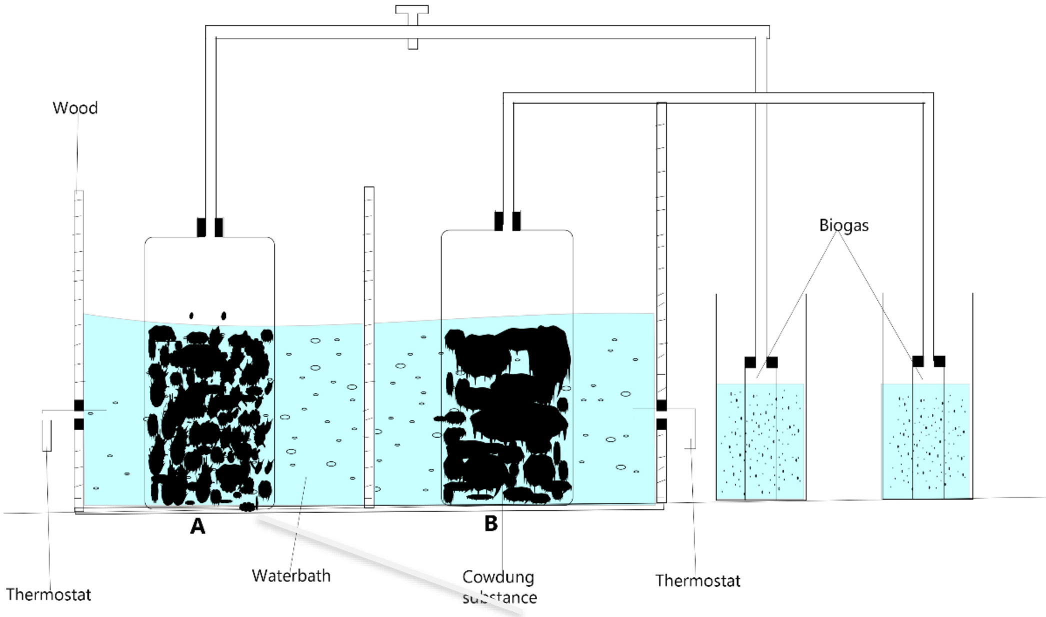

Figure 1: Experiment set up

The responses of the performance of the processes to changes in temperature were investigated in the two reactors A and B; A with temperatures being adjusted from the mesophillic to thermophillic range (37° C to 55°C) and B in a counter trend (55 °C to 37°C). Forced temperature variations were imposed on the digesters using the same mixture of manure in a semi-continuous process in both reactors. A thermostatically controlled water bath was used to maintain the temperature in the digesters at the desired level. The water bath was built out of plywood and was divided into two watertight compartments so that two experiments could be run simultaneously at different temperatures. The temperature of the 37°C (mesophillic) reactor was increased up to 55°C gradually by 3°C at intervals of 3 to 4 days, while the temperature of the 55°C (thermophilic) reactor was decreased until it reached 37°C again by 3°C at the same interval. After each temperature change the reactor was left at the new temperature until a steady state was achieved. This took at least 3-4 days before the next temperature shift. The 37°C reactor was operated at 37, 40, 43, 46, 49, 52 and 55°C for 3, 4, 4, 3, 4, 4 and 3 days, respectively. The 55°C reactor was operated at 55, 52, 49, 46, 43, 40 and 37°C for 4, 3, 4, 4, 3, 3 and 4 days, respectively. It was considered that a steady state had been achieved when the levels of biogas production rate varied by less than 3% for about 4-6 hours.

2.2.2 Chemical analysis

The gas volume was measured using displacement of acidified water (pH 2-3) and methane percentage composition was measured using an Orsat analyzer. For methane (CH_4) analysis, the reagent used was potassium hydroxide solution 400 g/dm3, with absorbing power of 40 ml/CH_4 per dm3 of solution. The percentage by volume of methane in each gas sample produced was calculated as follows:

$$\text{Volume of constituent} = V_1 - V_2 \qquad (1)$$

Where V_1 = burette reading (ml) before removal of methane,
V_2 = burette reading (ml) after removal of methane.

$$\text{Percentage of methane} = [(V1-V2)/V1]\ 100 \qquad (2)$$

3.0 RESULTS

The responses of the performance of the processes to changes in temperature were investigated in the 37°C and 55°C reactors (A and B respectively) at a retention time of 22 days. After changing the temperature, only minor changes in the operating processes were observed in phase 1 with either reactor.

3.1 Effect of temperature shifts on the performance of the mesophillic to thermophillic reactor.

The results illustrate that the performance of reactor A changed insignificantly in terms of any of the measured parameters as the temperature was raised to 40°C and 43°C. Biogas production was 0.46 - 0.58 L of gas/day and methane % composition 54-60% as shown in Figure. 2. For the first 2 days the biogas production was approximately 0.55 -0.56 L/day which is fairly close to the peak value of 0.58 L/Day recorded on day 3. The methane percentage composition for the first 2 days was 32 %. However, a sharp drop in the methane composition was realized on day 3 that had the peak biogas volume. The subsequent methane percentage compositions from day 4 to day 8 increased tremendously with further fluctuations realized there after. The peak value of the methane composition was attained on day 17.

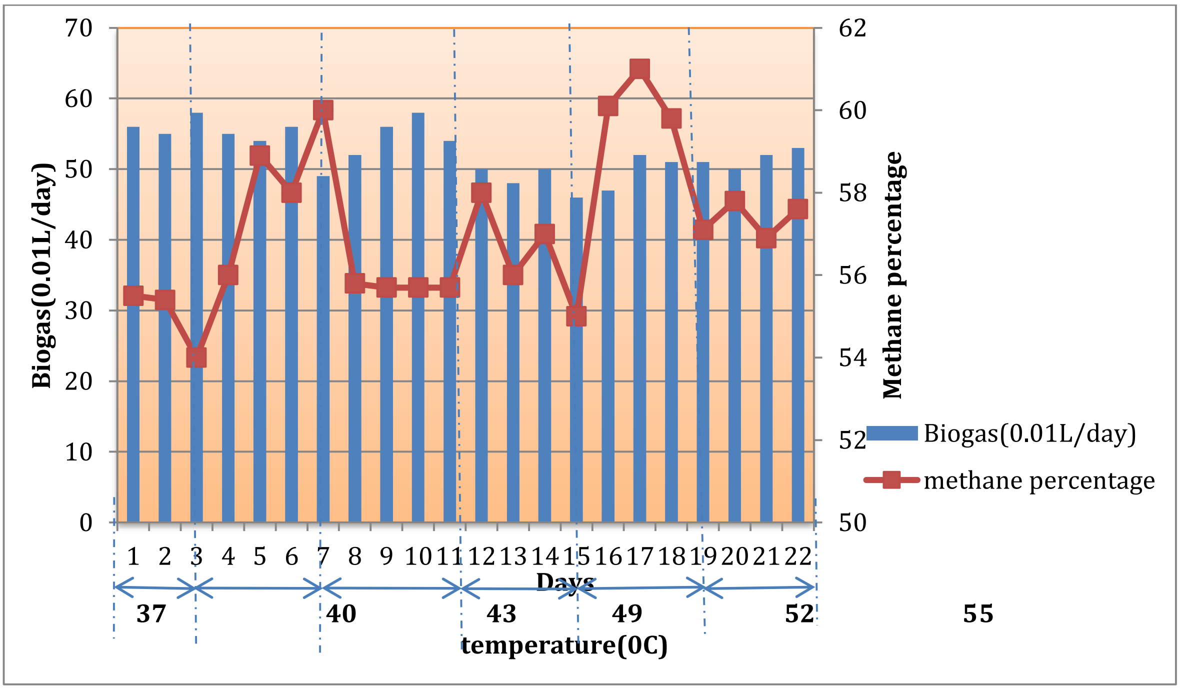

Figure 2: Biogas output and methane % variation with temperature for reactor A

3.2 Effect of temperature shifts on the performance of the thermophillic to mesophillic reactor.

The 55°C reactor, operated over the reducing temperature range of 52°C, 49°C and 46°C also produced only minor changes as shown in Figure.3. The biogas production varied from 0.48 - 0.56 L/day and methane production ranged from 0.292-0.342 L/day. However, when the temperature was reduced from 46°C to 43°C the efficiency of the process became lower with a significant drop in methane (0.193 L/day) and biogas productions (0.41 L of gas/day). At each 3°C temperature shift from 55°C to 52°C, 49°C, 46°C and 43°C, there was a rapid initial drop in biogas production rate that was quickly reversed over a few days.

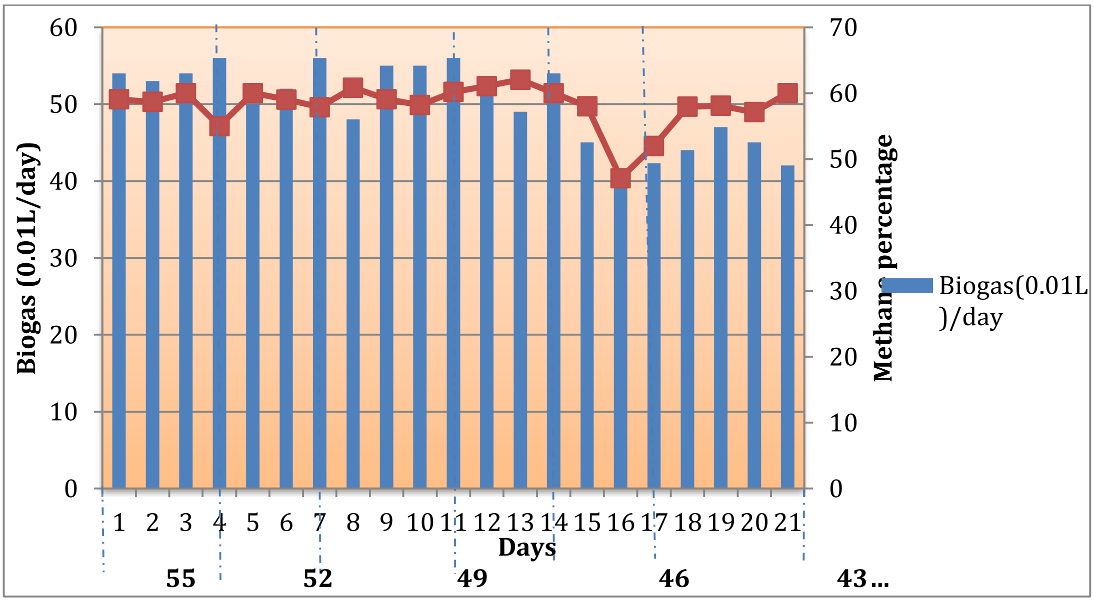

Figure 3: Biogas output and methane % variation with temperature for reactor B

4.0 DISCUSSION OF RESULTS

These results showed insignificant shift in the biogas output with changes in temperature for both the mesophillic and thermophillic reactors. The 55°C reactor was quite sensitive to the temperature disturbances, probably due to induction of a temporary unbalance of the microorganisms in the reactor. For reactor A: The drop in the methane percentage composition could be due to decrease in the number of methanogens that had developed due to the ambient environment the cow dung had been in for 2 weeks prior to the study (Tian et al., 2018). These had been adaptive to room temperatures (25 to 28 °C) and hence 37 °C could have been harsh for them. Later on thermotolerant mesophiles developed hence the increased methane percentage composition. These mesophiles are able to withstand thermophilic conditions but are not thermophiles hence the reason for the drop in Methane composition as temperatures shift from 40 to 43 °C(Tian et al., 2018). Likewise the drop in biogas output and the methane percentage composition for reactor B could have been due to the shift from thermophillic to mesophillic conditions, which affected the thermophiles.

Speece (1996) reported that methanogens are more sensitive to temperature changes than acidogens. It maybe that the rate at which the methanogens converted the fatty acids to methane was initially reduced far more than the rate at which the acidogens produced acids whenever a temperature shift occurred. Also the methane production and yields did not vary significantly at these different temperatures. It seems therefore that temperature shifts do not directly affect the gas composition. From these results, we can conclude that the microorganisms present in these reactors must have a tolerance for a fairly wide range of temperatures. Boušková, Dohányos, Schmidt, & Angelidaki, (2005) proved that a one time shift from mesophillic to thermophillic temperature range is a faster strategy than gradual increase of temperature increments. This may be attributed to the presence of thermotolerant organisms that can quickly adapt to any newly imposed temperature change (Salam, Biswas, & Rabbi, 2015). Chen (1983) reported that the development of a bacterial community involved in the degradative system could be related to the percentage of mesophilic and thermophilic bacteria in the initial sludge. Moreover manure fibers provide the surface area for LCFAs to adsorb and decrease their concentration in solution, thereby providing stability to the thermophilic process (Labatut, Angenent, & Scott, 2014). (Tian et al., 2018)also suggested that an upward temperature shift might lead to the development of a culture dominated by thermotolerant mesophilic organism rather than true thermophiles. Moreover, both reactors could be operated successfully at 43°C, which is considered to be the optimal changeover temperature from mesophiles to thermophiles (Tian et al., 2018). An option of catalyzing the system maintained at 40-43 °C throughout could be viable so as to maintain the bacteria community that is already adaptive to this temperature (Salam et al., 2015).

However, this could be different for some few substrates like duck weed which was reported to produce more biogas in the mesophillic range (Ramaraj & Unpaprom, 2016).

4.1 Policy implications of the study

In bid to devise alternative energy sources under the rural electrification initiative by the government of Uganda, biogas digesters should be maintained under thermophillic conditions for maximum biogas output. Therefore there is need for mass sensitization for both commercial and home use biogas plant maintainers on how to monitor, adjust and maintain thermophillic temperature regimes of the digesters.

4.2 Limitations of the study

Conducting experiments was so cumbersome and a lot of time was spent manually monitoring parametric changes due to lack of an automated lab scale digester.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Thermophillic conditions (40 - 46°C) fairly favor biogas production from cow dung as a substrate. This is because peak values for biogas produced and the methane percentage compositions were realized in this range. However operating a digester at least at 37°C can be effective since the changes in temperatures gave no significant changes in the amount of biogas and relative percentage composition of methane. The changes in temperature do not have significant changes on the methane composition of biogas. For any temperature change there are always smaller drops in methane composition that are corrected to normal values in less than a day. Increasing temperature increases the rate at which biogas is produced.

5.2 Recommendations

Biogas digesters should be maintained at thermophillic conditions since they are ideal for high production rates and digesters are capable of producing thermotolerant mesophiles. This can be done by concentrating radiation from the sun on to digesters by use of solar collectors or by use of any other controlled heat source.

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Vol 4, 2019 Issue, ISSN 2001-2837, Pages 1-89

Carbon to Nitrogen ratio variation effects on biogas systems performance in Uganda: A facile substrate based comparative study

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ABSTRACT

This study aimed at finding out the effects changes in Carbon to Nitrogen (C/N) ratios have on biogas systems performance particularly in terms of the amount of biogas output, the methane percentage composition and the time the feed stocks remain active through the study. This research work presents the experimental results of the anaerobic digestion of various types of biomasses basing on C/N ratios. The animal manure substrates used in this study were; poultry litter (PL), cow dung (CD), mixture of poultry litter and cow dung (M_1), poultry litter mixed with piggery manure (M_2), cow dung mixed with piggery manure (M_3). The C/N ratios of the substrates were 15.00, 22.00, 1.04, 16.00 and 5.50 respectively. These substrates were maintained at mesophillic temperatures (35^0C) separately. Particular attention was focused on the productivity of the substrates, measuring daily biogas production by the method of downward displacement of water and methane composition using an Orsat gas for 29 days. **M_2** gave the highest values in terms of both the peak values of biogas and methane (0.76 L and 0.446 L respectively) and the highest total biogas output as well at 8.96L. CD took the longest biogas production time and showed even potential to go beyond the set experimental time of 29 days though it took comparatively longer to start. CD had the second highest in total biogas output at 6.27L of biogas followed by PL at 4.25L, M_3 at 2.70L and M1 at 1.95L. The cumulative methane composition correlated well with the total biogas output with only M_3 giving a higher methane output of 0.68L compared to PL at 0.25L. In this research, it was found that the C/N ratio was proportional to the biogas system active time as well as the total biogas output.

Keywords: *Renewable energy, Biogas, C/N ratio, substrate*

1.0 INTRODUCTION

1.1 Back ground

The control of atmospheric emissions of greenhouse and other gases and substances in Uganda will increasingly have to be based on efficiency in energy production, transmission, distribution and consumption (World Bank, 2005). Modern bioenergy technologies such as biomass gasification, cogeneration, biogas generation, biomass densification, and energy-efficient cooking stoves have been introduced in Uganda but have certainly not been widely disseminated (Okello, Pindozzi, Faugno, & Boccia, 2013).

Uganda has the potential to produce about 1,258.37 million m3 of biogas annually, which is equivalent to 25.17 PJ of energy from livestock wastes (Owusu & Banadda, 2017). Appropriate raw material for biogas production must involve organic material that is suitable for anaerobic digestion. The energy production potential of feedstock depends on the type, level of processing or pre-treatment and concentration of biodegradable material. The C/N ratio, which is fully written as carbon to nitrogen ratio is regarded as the ratio of the elemental carbon present in the material to the elemental nitrogen present in the material. Different materials have their C/N ratio, but mixture of different materials can alter the overall C/N ratio of the total feedstock (Okonkwo, Onokpite, & Onokwai, 2018). A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion(Fantozzi & Buratti, 2009). However efforts to have substrates match this range are still lacking (Dandikas, Heuwinkel, Lichti, Drewes, & Koch, 2014). In Uganda the commonest biogas feedstock are; cow dung, Piggery manure and Poultry litter(Owusu & Banadda, 2017). It still remains abstract to many biogas operators; both domestic and commercial on which substrate or co-substrate to adopt basing on the retention time, biogas output and methane percentage composition yet this is key(Mutai et al., 2016).

1.2 Problem Statement

The global depletion of energy sources and the adverse effects of fossil fuels on the environment pose a challenge to devise alternative energy sources. Among the efforts to combat the problem is the use of renewable energy sources of which biogas systems are part. In Uganda, the spread of this technology is still limited. Most of the biogas systems are no longer functional and those in operation are not performing to the expected outputs (Mutai et al., 2016). Besides the economic and social factors is the poor control of anaerobic digestion parameters which are the pinnacle for any biogas system performance (Labatut, Angenent, & Scott, 2014; Ziganshin, Liebetrau, Pröter, & Kleinsteuber, 2013). Since most of the biogas systems are operated at home level by mostly non-technical users, they are not aware of the appropriate C/N ratios for effective system performance. This research aimed at evaluating the performance of biogas systems with varying C/N ratios based on substrates.

1.3 Purpose

The core purpose of this study was to identify the appropriate C/N ratio ranges for the chemical reactions involved in each stage of biogas production and hence ascertain the effect C/N ratio has on percentage composition of the biogas output.

1.4 Research Question

What are the effects of C/N ratio variations on the performance of biogas systems in Uganda?

1.5 Scope

This study evaluated the performance of different substrates with varying C/N ratios in terms of biogas out puts and the methane percentage composition in the biogas.

1.6 Organization of the article

The background to the research problem and the significance of the study are presented in section 1. Section 2 entails the methods and materials used. These include the equipment adopted as digesters, the collection and preparation of the feedstocks and the analysis of the substrates. The results from the study are presented in section 3 and discussions of the same are presented in section 4.

2.0 METHODS AND MATERIALS

2.1 Feed Preparation

In this study the following animal manure substrates were analyzed: Poultry litter (PL) mixed with water, Cow dung (CD) mixed with water, mixture of poultry litter and piggery manure from a local digestion Plant (M1), cow dung mixed with piggery manure (M2), Poultry litter mixed with piggery manure (M3). These substrates were chosen because they are the commonest feedstock for biogas digesters in Uganda and their C/N ratios are known. The proportions in which the substrates could be mixed to attain particular C/N ratios were standard and this helped to prepare the samples and widen the range for the analysis used in this study (Table 2).

Table 1: proximate and ultimate analysis results for the substrates(Fantozzi & Buratti, 2009)**.**

Element composition	Substrate				
	Poultry litter	Cow dung	M_1	M_2	M_3
C/N ratio	15.00	22.00	1.04	16.00	5.50

The poultry litter and piggery manure were collected from a farm in Kiwawu Village - Malangala Sub County in Mityana district-Central Uganda. Fresh cow dung was collected using a wheelbarrow from an abattoir near Malangala Sub-County headquarters in Mityana district, Uganda. It was sorted to remove other indigestible materials like stones and metals. It was then kept covered in a heap with polythene bags at ambient temperature (25±20C) for two weeks before the experiment.

Table 2: Masses of substrates in kg used to prepare feed stock mixtures

Masses of substrates in g used to prepare M_1, M_2 and M_3.	Substrate mixture		
	M_1	M_2	M_3
Poultry litter	1.0	1.4	-
Cow dung	3.0	-	2.0
Piggery manure	-	1.8	1.0
Water [b]	1.0	1.8	2.0

[b]= measured in litres during the experiment

2.2 Equipment

The reactors used in this experiment were five 250cm3 Perspex cylindrical flasks tightly sealed with rubber corks and labeled PL, CD, M1, M2 and M3 corresponding to the feed stock put in the reactor. The gas given off was tapped off through rubber tubes to the disposable calibrated syringes partially under water and held by retort stands. The outlets of the syringes were blocked with clipped rubber tubes. After 6-8 days the air inside the containers had to be released so that only pure gas was inside. It had to be ensured that the syringes were filled with water before releasing. The tube clips were loosened to let the air leak out until it began to smell. Sampling and measurements started after 8-13 days and were taken daily till the reactors went passive and those that were still active after the 29h day had to be terminated. Shaking the flasks twice a day in the morning and evening hours always did the agitation. A constant temperature of 35° C (mesophillic) was maintained through a thermostatically controlled water bath for each reactor for a total of 29 days.

2.3 Chemical Analysis

The biogas composition was analysed using an Orsat gas analyser (model; A-00621-AO). The gas analyser had been calibrated 2 months before the study. Sampling was done by sucking through the cork using a 5 ml medical syringe and pH was measured using a pH metre (AR20 pH/conductivity meter).

3.0 RESULTS

3.1 Biogas production rate at the start

All the reactors were inactive for the first days with the earliest going active on day 7 and the latest on day 14 as shown in Figure 1 since no bacteria had accumulated due to no sludge added. Even still all substrates took 2-3 days less time compared to the individual substrate wait times available in literature before start of biogas production. This is because the substrates had been kept in oxygen free cool environment for two weeks before the experiment. It was noted that some reactors continued for 1 to 2 days producing gas with no methane before they completely terminated. This could signify the exhaustion of carbon that takes part in methane formation. This was evident in the reactors with low C/N ratios (M_3, M_1 and PL) (Figure 1).

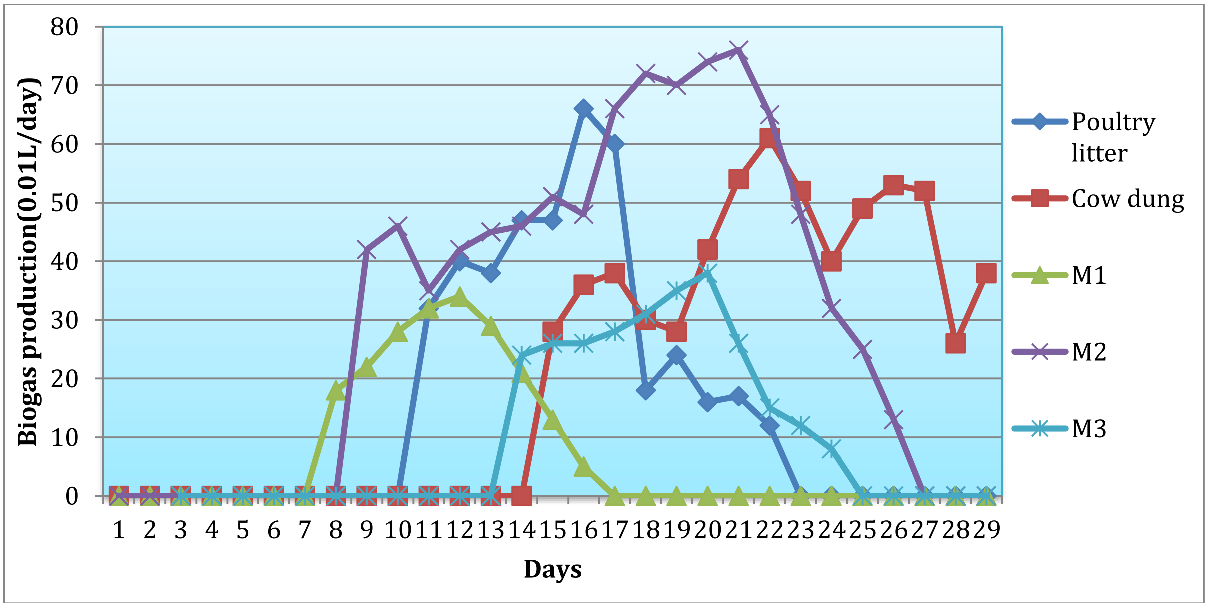

Figure 1: Daily biogas production from different substrates

3.2 Progressive biogas production rates and methane % compositions

M_1 was the first to produce gas on day 8 but in very low amounts compared to **CD, PL and M_2**. It showed a steady increase in biogas production to day 12 then it started to reduce. This showed the least number of days of active gas production (9 days). Its biogas production level peaked (0.32L/day) on day 11 of digestion and then gradually decreased to 0.05L/day on day 16 after which it completely ceased. **M_2** gave the highest values in terms of both the peak values of biogas and methane (0.76 L and 0.446 L respectively). The total biogas production was 8.96 L of gas the highest of the five reactors. From those values it could be considered successful even though it terminated earlier than that of pure cow dung. Poultry Litter (**PL**) test started producing biogas on day 11 in good amounts, showed steady increase up to its peak on day 16 (0.66 L of gas/day) after which it started to decrease and ceased on day 22. Its methane production was so insignificant, its composition ranged from 4.6 to 9.7% that is so low for gas combustion (Figure 3).

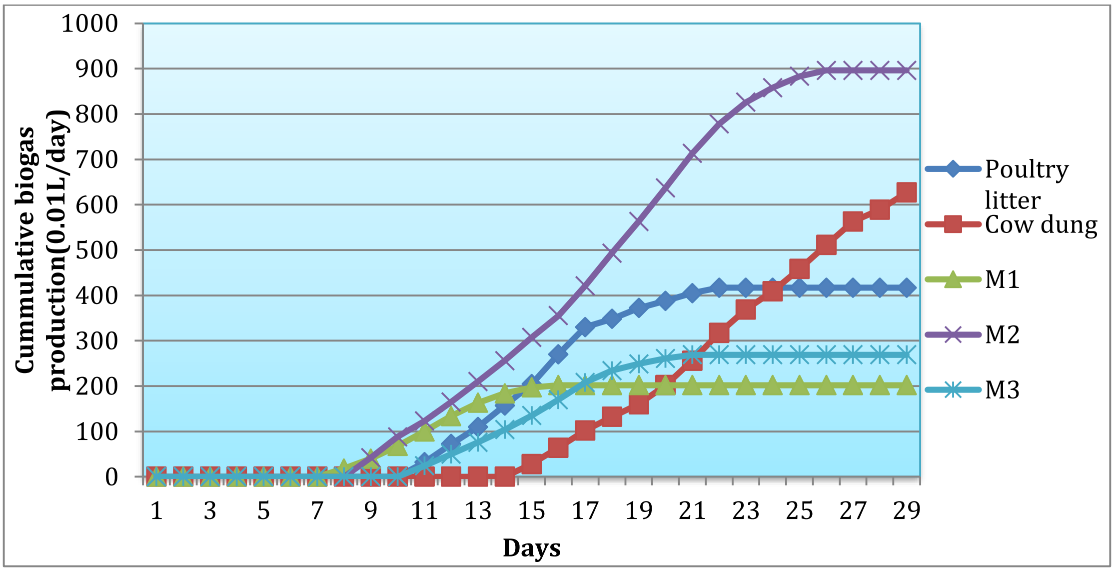

Figure 2: Cumulative biogas production per substrate

The reactor with Cow dung (**CD**) took comparatively longer time for biogas production to start (day 14), it showed the highest active time that even its production was terminated due to time factor. It could go over 29 days unlike the rest that naturally terminated. The biogas output from cow dung reactor was 0.28 – 0.53 L/day. It gave the second highest total biogas production (6.27 L of gas) for the 29 days of monitoring (Figure 2). Its biogas peak value (0.61 L/day) was on day 22 and methane peak (0.314 L/day) on day 21 (Figure 3). **M_3** was insignificant in its biogas output though better than the **PL** and **M_1**. It produced the peak biogas amount 2 days to termination and in the last two days the biogas had no methane at all. For the 29 days M_2 had the highest methane produced as shown in Figure. This correlated well with the total biogas output.

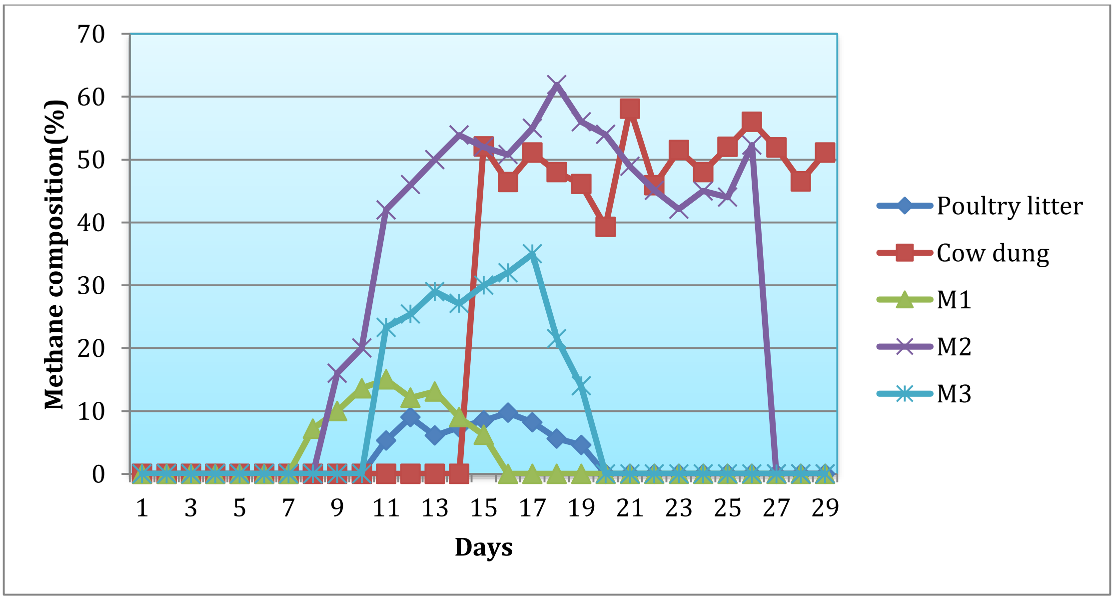

Figure 3: Methane percentage composition per substrate

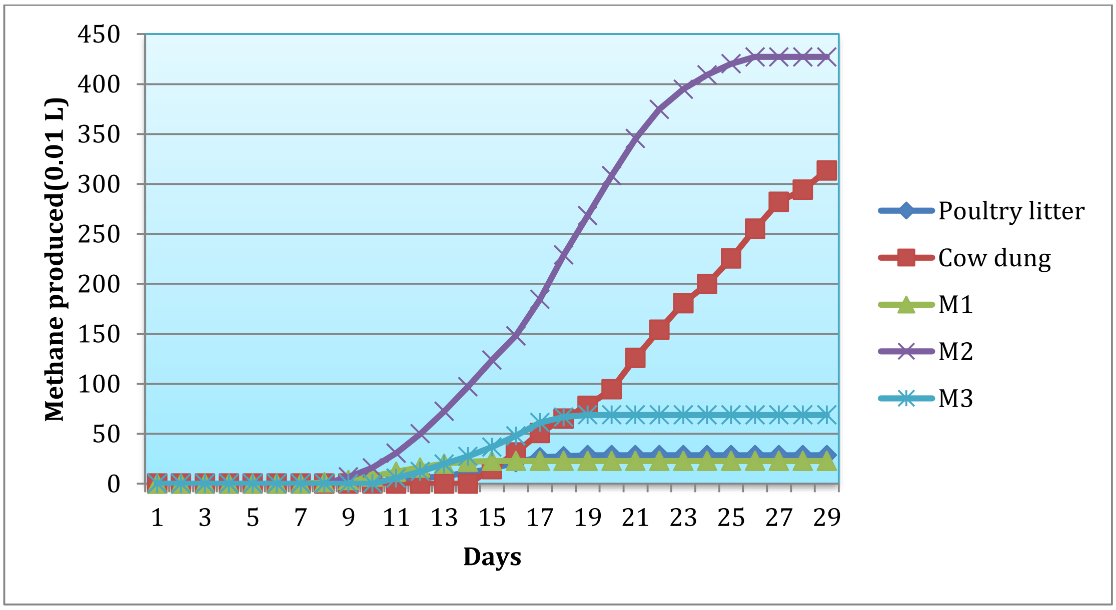

Figure 4: Cumulative methane composition per substrate

4.0 DISCUSSION OF RESULTS

4.1 Biogas production

The passivity of the reactors during the first days could be attributed to the dissolved oxygen in the substrates that impeded aerobic digestion(Okonkwo et al., 2018). Although an increasing biogas production was observed from all test units during the first days after production began, there was not much methane produced during those days. This is due to the oxygen that dissolved in the water used in preparing these feeds and also remained in the pore spaces of the bio solid, the most of biogas production during the first days could have probably come not through anaerobic digestion but aerobic or anoxic degradation(Okonkwo *et al.*, 2018). CD had the longest digester active time. It was terminated at day 29 while the rest naturally ceased to produce any biogas before day 29. This is attributed to the highest C/N ratio implying anaerobes had more carbon to act on. M_2 produced more biogas than CD due to the combination of both poultry litter and piggery manure that are excreta of non-ruminants. This implies that starch for these substrates was still in abundance for bacteria to act on and also effect methanogen growth(Alfa, Dahunsi, Iorhemen, Okafor, & Ajayi, 2014). The dissipation of the readily degradable materials may have caused temporal biogas production decrease approximately halfway their retention times (Demirer & Chen, 2008; Lu *et al.*, 2007).

4.2 Biogas methane composition

All the tests gave relatively low methane composition peak values compared to those obtained by other scholars(Zhou, Zhang, & Dong, 2012). This could have been due to the maintenance of the reactors in the same temperature range that some bacterial consortium that could convert intermediate products of the bio- chemical reactions could not easily adapt to it (Labatut et al., 2014; Lohani, Wang, Bergland, Khanal, & Bakke, 2018). Methane production increased progressively generally for all the substrates. This is because the aerobic bacteria were being substituted by acid forming bacteria and the carbon to be acted on was still abundant. This progressed up to peak values after which it gradually dropped. This is because the carbon content reduces over time and the C/N ratio reduces up to when the bacteria feeding more on Nitrogen suppress those that act on carbon. It is pertinent to co-digest the animal wastes with crops for better methane yield (Nges, Escobar, Fu, & Björnsson, 2012; Zhou et al., 2012). In the same way this can help sustain better biogas production even with biogas latrines solving an issue raised by Mutai *et al.*, (2016).

4.3 Policy implications of the study

It is pertinent to change the design of digesters to have methanization chambers where substrates can be transferred after the first 11-12 days of digestion. This shall enable tapping of high quality biogas.

4.4 Limitations of the study

The C/N ratios of substrates were based on theoretical values from past studies. They were not determined in this study. The compositions of animal manure are dependent on a number of factors among which are the feeds and the weather conditions they are subjected to.

5.0 CONCLUSONS AND RECOMMENDATIONS

5.1 Conclusions

The higher the C/N ratio the higher the biogas produced. However the digesters may produce high biogas output but with relatively low methane content.

Animal manure can be improved as a substrate regarding production of higher biogas amounts with better methane composition by mixing it with crop residues.

Substrates of high C/N ratio may produce unexpectedly lower biogas and lower methane percentage compositions if maintained at the same temperature regimes.

5.2 Recommendations

It is appropriate to separate digesters such that after the first days of digestion the feedstock can be delivered to a methanization chamber where good methane compositions can be tapped. This helps also to reduce time lags in case used up slurry has to be removed in case of batch fed digesters.

Low C/N ratio substrates are more suitable for continuously fed digesters than batch fed. This is because continuous feeding can help maintain a level of carbon content despite the depletion in a short time.

If low C/N ratio substrates are to be used in biogas production they should be inoculated with sludge to reactivate digestion by introducing new acid forming bacteria.

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Vol 4, 2019 Issue, ISSN 2001-2837, Pages 1-89

Digitization of Agricultural Extension Services: A case of Mobile Phone-based Extension Delivery in Central Uganda

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ABSTRACT

Agricultural extension services are essential for effective production at household level. Over the years, traditional extension delivery has metamorphosed to digitization of extension services including mobile phone-based platforms. Mobile phone-based extension delivery involves lay extension agents that use mobile applications; customised on a smartphone to disseminate agricultural knowledge and practices to last mile farmers in real time. This paper examines the mobile phone-based agricultural extension approach used in Central Uganda. I adopted agency-structure theory to analyse three research questions. Foremost, what kind of information is digitized on a mobile phone-based platform? Second, which extension services are adopted by smallholder farmers? Lastly, what are the motivational factors for farmers to adopt good agricultural practices disseminated through a digital platform? The study used a mixed methods research design; with 390 surveys, key informant interviews and focus group discussions. Study results revealed that five broader categories of extension information are digitized namely: agronomic, climate change, market information, financial services and others generalised practices. The perceived ease of use, usefulness and expected economic gains were the main drivers for adoption of mobile phone-based extension services. Agronomic practices were adopted more than others due to the perceived direct influence on agriculture production and productivity, as well as expected economic returns. Regular and intense interaction of farmers with extension agents, low cost information, use of pragmatic skills development techniques, social influence of extension agent to farmers and farmers' social networks also swayed adoption. However, amidst the desire to adopt good agricultural practices, smallholder farmers are constrained by poverty, adverse effects of climate change and technical know-how. Thus, to enhance farmers' use and adoption of digitized extension services, farmers' personal resources, social networks, a web of community extension agents and structures of producer organisations should be harnessed and strengthened.

Key words: Digitization, Mobile phone, Agriculture extension, smallholder farmers, agency-structure

1.0 INTRODUCTION

Agricultural extension services are essential for effective production and productivity at household level. Extension service delivery is a channel for disseminating innovation, expert knowledge and practices to a wider audience including farmer peer learning, farmer group networks, extension workers and farmers interface and feedback mechanism (Christoplos, 2010; Christoplos & Farrington, 2004; Davis, 2008; Hakiza, Odongola, Mugisha, & Semana, 2004; Isubikalu, 2007; MAAIF, 2016; McCole, Culbertson, Suvedi, & McNamara, 2014; Musemakweri, 2007; Vignare, 2013). Extension services enable farmers to acquire new products, services, practices and acquire inputs for better agriculture performance.

For the past four decades, Uganda's extension system has evolved with several approaches adopted at different historical moments according to changing governments and policies.

Extension approaches have revolved around government regulation, advisory, educational and farmer led approaches to disseminate technologies (Agwaru, Matsiko, & Delve, 2004; Benin et al., 2011; Hakiza et al., 2004; Isubikalu, 2007; Musemakweri, 2007; Semana, 1999; Wairimu, Christoplos, & Hilhorst, 2016). For example, in 1998 to 2002 there was a paradigm shift in extension delivery; with pluralisation of extension including players from civil society organisations (CSOs), government and private service providers (Semana, 1999). Based on the previous experiences with mixed challenges and missed opportunities within extension delivery, the Plan for the Modernization of Agriculture (PMA) was instituted. Later National Agriculture Advisory Services (NAADS) program mandated by the NAADS ACT 2001, as a campaigner for agricultural extension service delivery in Uganda (Bahiigwa, Rigby, & Woodhouse, 2005; Benin et al., 2011; Davis, 2008; Isubikalu, 2007; MAAIF, 2010; Ninsiima, 2015; Semana, 1999; Wairimu et al., 2016). Nevertheless, NAADS has had its share of challenges such as; mismanagement of funds, policy uncertainty, political interference, embezzlement, under funding, high rate of farmer to extension workers, and exclusion of most farmers: focuses on economically active farmers as oppose to majority of poor smallholder farmers (McCole et al., 2014; Naluwairo, 2011).

Henceforth over the years, traditional extension delivery has metamorphosed to digitization of extension services including mobile phone-based platforms. The first mobile phone-based extension intervention was developed and implemented by Grameen Foundation with the Village Phone network. In partnership with MTN Uganda and Google, Grameen Foundation leveraged MTN’s network of 35,000 public phone operators to test and deliver mobile information services to rural communities (Gantt & Cantor, 2010; Okyere & Mekonnen, 2012). In addition, a network of Community Knowledge Workers (CKWs) were identified, recruited and trained as mobile phone-based lay extension agents within their communities (Gantt & Cantor, 2010; Kimbowa, 2015; McCole et al., 2014; Ninsiima, 2015). The CKW experience precipitated other players to undertake digitized extension delivery approaches. A case in point is the Village Enterprise Agent (VEA) model implemented by the Sustainable Enterprises for Trade Engagement project in central Uganda; in the districts of Masaka, Kalungu, Lwengo, Bukomansimbi, Kyotera and Lyantonde (Mugabi, State, Omona, & Jansson, 2018).

Since 2014, Lutheran World Relief (LWR), her partners the Community Enterprises Development Network (CEDO) and Gutsinda Development Group rolled out a mobile phone-based agricultural extension approach using lay persons branded as Village Enterprise Agents (VEAs). Using smartphones reloaded with agriculture content inbuilt in the Kulima Application, VEAs disseminate agriculture information to rural smallholder farmers (Kimbowa, 2015; Mugabi et al., 2018). In response farmers are expected to adopt extension knowledge so as to improve on-farm production and productivity. The digitization of extension services is intended to reduce on the deficits in traditional extension service delivery characterised by very low extension worker to farmer ratio. For example, in Uganda extension officer to farmers ratio is at 1:2,500 against the FAO recommended ratio of 1:400 (Ongachi, Richard Onwonga, Hillary Nyanganga, & Okry, 2017). In essence VEAs are expected to mitigate the extension delivery gap, since they are farmers themselves, live in proximity to their peers as opposed to extension officers that are based at sub-county and district local governments.

1.1 *Kulima* Mobile phone-based Extension Platform

Gutsinda Development Group has put information in the hands of rural communities by developing and deploying *Kulima* mobile phone-based Platform. The *Kulima* application features an agricultural library with information on farming techniques across different value chains (Gutsinda, 2014). *Kulima* platform is named after a Luganda word *Kulima* which means to till or plough. *Kulima* mobile platform integrates image and voice capture to assist explaining practical good agricultural practices to farmers. The platform content package is designed in English language but translated into Luganda (appropriate indigenous dialect) by VEAs during dissemination session (Mugabi et al., 2018). VEAs deliver agricultural information in a style described as verbally, motion mimic, physical and written (Fangohoi, Sugiyanto, Keppi, & Edi Dwi, 2017). At a click VEAs share information with farmers during planned farmer visits and within groups. Below is figure 1 showing the screenshoot of *Kulima* mobile phone-based platform.

Figure 1: *Kulima* Mobile Platform
Sources: Adopted from Gutsinda (2014)

However, farmers' access to digitized extension services is not an end in itself, rather adoption of knowledge and practices is critical to improve on the quantity and quality of yields. Previous studies have asserted that end users' resistance or acceptance of the technology is a major driver for its adoption or non-adoption (Bell, 2015; Murendo, Wollni, de Brauw, & Mugabi, 2015; Mustonen-Ollila & Lyytinen, 2003). This though depends on the kind of technology infrastructure: where, for whom, by whom and for what communication and information is used, what is referred to as technology developers' and end users' perspective (Castells & Cardoso, 2006). Against this background, this article addresses three research questions. First, what kind of information is digitized on *Kulima* mobile phone-based platform? Second, which extension services are adopted by smallholder farmers? Lastly, what are the motivational factors for farmers to adopt good agricultural practices disseminated through digital platform?

1.2 THEORETICAL FRAMEWORK

Anchored in the above research questions, I adopted the actor oriented agency-structure theory to analyse study findings. Contrary to the structural theories, agency-structure theory puts a central position to social actors as conscious, active, powerful and constructive within a given social environment (Long, 1990). I apply the agency-structure theory to analyse the agency of smallholder farmers as end users of digital extension services. The theory was used as an analytical framework to discuss the farmers' consciousness in making decisions about access to and use of particular mobile phone-based extension knowledge and practices. The theory was also applied to explain the structures that enable farmers' adoption of digitized extension services. Two theoretical concepts were used namely; the agency (capacity and knowledgeability) and subjective-objective duality (Bourdieu, 1977; King, 2000; Long, 1990, 2001; Sewell, 1992). The focus is on social actors with capacity to process social experience, devise ways of coping with life, even under the most extreme forms of coercion, uncertainty and the other constraints (Long, 1990). The concept of agency is premised on the notion that human beings are gifted by nature; with reasoning capacity and a will to make conscious decisions whether good or bad. The agency attempt to solve problems, learn how to intervene in the flow of social events around them, but this depends upon the capability of the individual to make a difference to a pre-existing state of affairs or course of events, also referred to as agent power (Giddens, 1984). In this study, the focus is on the agency of smallholder farmers within a micro household environment as opposed to institutional and organizational levels.

The agency is however exercised within a duality relationship; a given structural boundaries (social context) and rules of the game that have both a constraining and enabling effect on social behaviour of actors (Giddens, 1984; King, 2000; Long, 1990, 2001; Sewell, 1992). In addition, though human beings live within social boundaries, at the same time they reconstruct the practices of the structure (Long, 1990, 2001). The wellbeing of actors is a relationship between the structure and the agency; described as subjective-objective dualism (Bourdieu, 1977; King, 2000). Social structures are both constituted by human agency, and yet at the same time the very medium of this reconstitution (Giddens, 1984). Hence the agency of farmers functions along the social context of subjective; individual choices and actions, as well as structural boundaries. The duality relationship is not static though, rather it is fluid depending on how the actors constructs social reality to enhance her agency power. For example, smallholder farmers belong to social networks of groups as structures for diffusion of digitized extension services. Such structures operate within group dynamics, leadership and rules that are formulated by members themselves.

2.0 RESEARCH METHODS

The study adopted a mixed methods research design, combining both quantitative and qualitative methods and techniques in data collection and analysis. Specifically, I adopted the convergent parallel mixed methods (Creswell, 2014). The study involved 390 survey respondents, 9 key informant interviews and 7 focus group discussions (FGDs) conducted in central region. On one hand, the survey sample size of 390 participants was determined following the level of precision, level of confidence and degree of variability of the study populations (Israel, 1992).

The estimated number of farmers in central region (Masaka, Kyotera, Kalungu, Lyantonde and Lwengo districts) was 689,385 (UBOS, 2016), and out of which 17,000 had access to mobile phone-based extension services (Mugabi et al., 2018). In this case, I adopted Cochran equation to generate a representative sample (Cochran, 1963), to have a representative sample:

$$\mathbf{n_0} = \frac{Z^2pq}{e^2} \qquad (1)$$

Where $\mathbf{n_0}$ is the sample size, $\mathbf{Z^2}$ is the abscissa of the normal curve that cuts off an area at the tails (desired confidence level is 95 percent which 1.96 on Z table), **e** is the desired level of precision (5 percent), **p** is the estimated proportion of an attribute that is present in the population (smallholder farmers in Uganda accessing mobile phone 52 percent (UCC 2015), and **q** is 1-p. Thus, the calculated sample size was 384 smallholder farmers, which was slightly adjusted to 390. On the other hand, purposive sampling was used to select specific FGD and key informant interview participants with exceptional experience and knowledge about mobile phone-based agricultural extension approach.

The study area was purposively selected due to the unique mobile phone-based extension service delivery intervention implemented since 2014. The selected districts were part of the Sustainable Enterprises for Trade Engagement project which implemented the *Kulima* mobile extension approach. In this study, central region includes the current districts of Masaka, Kyotera, Lwengo, Lyantonde, Rakai, Bukomansimbi and Kalungu. Thus, the study used a convenient sample of households that had access to digitizes extension services. I used a convenient sample because of the uniqueness; not every farmer within the study area had access to mobile phone-based extension services, to apply all rules of randomisation.

On one hand, quantitative data was collected using smartphones with customised Open Data Kit (ODK) web-based mobile data collection technology. The data was directly uploaded to the electronic system using the Smartphones at the end of every survey interview. The uploaded data entries were then exported into IBM SPSS Windows 25.0 computer software for analysis. Qualitative data were analyzed using Nvivo12 Computer Assisted Qualitative Data Analysis Software; based on specific attributes, nodes, ties and relationships corresponding to the key research questions.

3.0 RESULTS AND DISCUSSION

3.1 Demographics and socio-economic characteristics of farmers

It is imperative to contextualise the study findings as far as socio-demographic characteristics of participants are concerned. In terms of sex composition, 52% and 48% were female and male participants respectively. Almost all farmers (99%) live in male headed households and only 1% were female headed. Household headship is important in this community because head of household is responsible for day-to-day running and decision making, though he or she may not necessarily be the main household income earner (UBOS, 2017). My study has majority male headed households compared to national statistics where male headed households are 68% and 32% female headed (UBOS, 2017). This is because the study was conducted in rural agrarian community which is predominantly patriarchal. As opposed to the national statistics that combined both rural and urban households.

The median age of farmers was 49 years; 77% were above 35 years, and 23% were young adults between 18 to 35 years. In addition, 68% had primary and below primary level of education, 27% had secondary level and only 5% had tertiary education (mostly certificate) after secondary level. It was also revealed that most farmers have limited landholdings: 69% had less than an acre (0.41 hectares), 28% had one to four acres (0.41 to 1.6 hectares) and only 3% own more than four acres (1.6 hectares). Farmers hardly hired land; with an average of only 0.34 acres (0.14 hectares) hired for agriculture. Notably, 81% of farmers are *mailo* land holders (tenants as bonafide occupants) and 11% freehold. There were 5% with private *mailo* and 3% hold leasehold land tenure systems. The above socio-economic characteristics are critical resources and structures that enable or hinder farmers to exercise their agency as far as adoption of digitized extension services is concerned. Farmers' socio-economic characteristics are resources that provide various options and opportunities to make informed decisions, influence change of attitude to participate in development including adoption of mobile phone-based good agricultural practices.

3.2 Digitized extension information on a mobile phone-based platform

The first research question was concerned with: what kind of information is digitized on a mobile phone-based platform? As a result, findings revealed five broader categories of extension information that were customized on *Kulima* mobile extension platform namely: agronomic, climate change, market information, financial services and others generalised practices. Digital agronomic information included all extension services related to site selection, planting materials, fertiliser application, spacing, weed control, crop management, pruning and pest and disease control among others. Climate change information included: weather information alerts, soil conservation, quality planting materials and agro-forestry. In addition, market information was concerned with post-harvest handling, storage, collective bulking and marketing through producer organisations. Financial services are associated with access to credit or agriculture financing and Village Saving and Loan Associations (VSLA). Lastly, other generalised extension services included record keeping, poultry and livestock management among others. To note however, *Kulima* mobile extension platform was lop-sided to crop production extension services more than livestock, fisheries and agro-forestry among other value chains. A review of *Kulima* mobile platform revealed considerable content packages based on mainly crop value chains such as banana, coffee, maize, rice and tomatoes. The digital agriculture library is tailored to the various crop seasonal calendar activities. Besides, key informants also underscored varied digitized extension services. For example, a male VEA (trained extension assistant) narrated that:

There is an application called *Kulima* where we find information concerning agriculture. For instance, about the growing of beans, knowing the different types of beans, the pests and diseases that attack the beans then I can go back to the farmer and see what is happening. The information is in English language that is easily understood. The information is sufficient enough; there is a lot of information in *Kulima* platform **(Male VEA, Kyotera District).**

The above narrative matches with the evidence in Figure 2 that shows a pictictorial demonstration of the various information digitized on *Kulima* mobile platform.

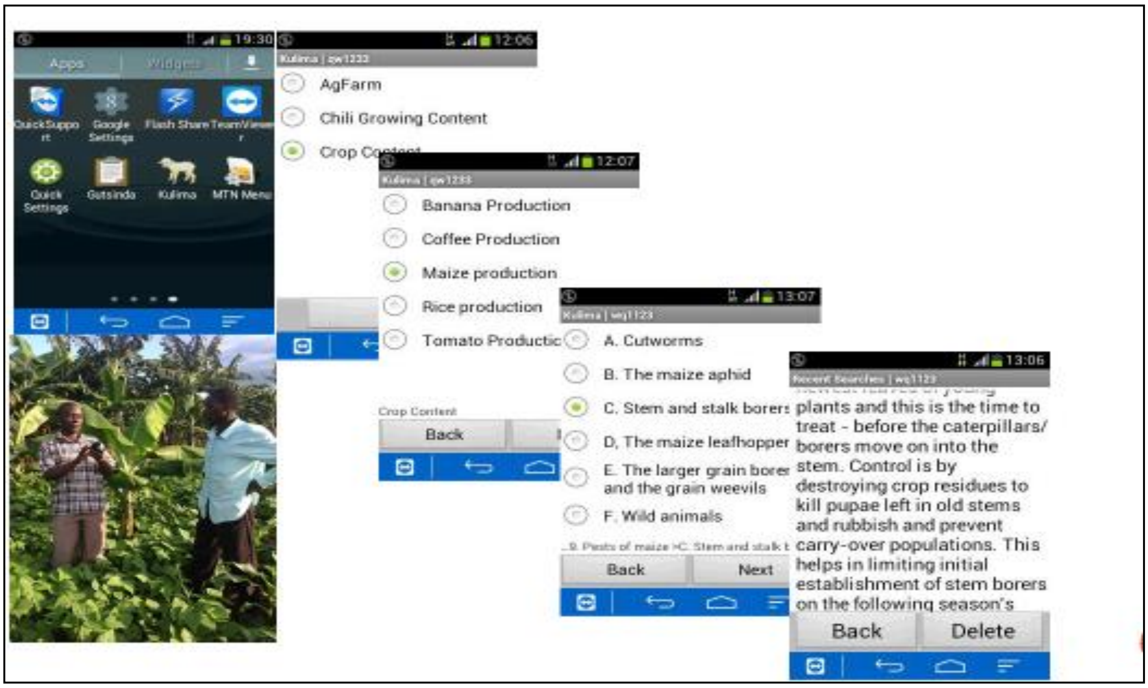

Figure 2: Information Disseminated to Farmers using *Kulima* Platform
Sources: Adapted from Gutsinda (2014)

From the above narrative and in figure 2 above, it is evident that the digitized extension information is mainly concerning crop production. The skewedness of *Kulima* mobile extension platform to crop production information is due to the fact that central region is predominant a crop production region. Studies have also made similar observation, historically, central region is an agricultural hub for crops and some livestock (Anderson, Learch, & Gardner, 2016; McCole et al., 2014; UBOS, 2014). Hence *Kulima* extension package also reflects the tradition extension systems that emphasise crop production extension service (agronomy), with less attention on financial services, climate changes and market information (Agwaru et al., 2004; Bell, 2015; Christoplos, 2010; Hakiza et al., 2004; MAAIF, 2010, 2016; May, Karugia, & Ndokweni, 2007; McCole et al., 2014; Naluwairo, 2011; Ragasa, John, Jose, & Thaddee, 2016; Vignare, 2013). However, agriculture is a very complex activity; it requires a balanced content package for farmers to receive extension services across all value chain. I argue that the content package digitized in *Kulima* platform was built on the traditional extension approaches that are based on agro-ecological production structures and social-cultural context of the area of study. In reality though, farmers engage in mixed farming; integrating crops and livestock, and intercropping of a variety of crops. Thus, the platform gives less options of extension services to meet the fused and ever changing extension needs of farmers.

3.3 Adopted digital extension knowledge and practices

VEAs disseminated mobile phone-based extension services on a presumption that farmers would in response adopt the good agricultural practices. Accordingly, the study sought to explore the digital extension services which were adopted by smallholder farmers. Adoption was analysed on the basis of disseminated digital extension services namely: agronomy, climate change, market information, financial services among other practices. It was found out that agronomic practices were the most adopted by smallholder farmers. The most adopted agronomic practices were; use of quality planting materials (85%), fertiliser and manure application (83%), pest and disease control (75%), site selection (68%) and crop management (66%) among others. As far as market information was concern, most farmers adopted good post-harvest handling practices (77%), but least got market information; better market options and prices. In addition, farmers' adoption of financial services through savings and access to loan facility within Village Savings and Loan Associations was at 57%. Knowledge and practices on climate change were the least adopted, as seen in table 1 below.

Table 1: Kind of Extension Information Adopted by farmers

No	*Good Agricultural Practices*	*Overall*
	Agronomic Practices	
1	Site Selection	**68%**
2	Good planting materials	**85%**
3	Crop management	**66%**
4	Agro-Inputs	**54%**
5	Use fertilizer & mature	**83%**
6	Pest and disease control	**75%**
	Market Information	

7	Market information	**28%**
8	Post-harvest handling	**77%**
	Climate Changes	
9	Soil Conversation	**28%**
11	Weather Information	**32%**
12	Tree planting	**24%**
	Financial Services	
13	Credit and VSLA	**57%**
	Other Practices	
14	Management of poultry	**19%**

Source: Research data, 2017/2018, *n=390*

In table 1 above, all extension information given by the VEAs was vital, however, adoption of climate change mitigation practices, market information, financial services were still low compared to agronomic practices. Adoption of agronomic practices were also highlighted by most FGD participants as the most adopted. A case in point was one participant who recounted that:

We have been trained and gained new ideas on agriculture especially coffee growing. We decided that every farmer in our group should have not less than two hundred plants of coffee. All the new ideas are then applied to our farms at home. We also adopt possible agronomic practices such as spacing, weeding, fertiliser/mature application, stamping pruning among others. Secondly, we used to lose a lot of water in our gardens but now we dig trenches in order to keep some water-water conservation ***(Male Farmer, Jjogoza Farmer field school, Kyotera District).***

The above findings demonstrated that while digital extension services are biased to crop agronomic practices, likewise farmers' adoption is skewed in the same direction. In this case, agronomic practices more than other extension services are perceived to improve on farm productivity. In essence, both digital extension and traditional extension approaches are based on rules of the game that are overly biased to agronomic practices. With less focus on practices to mitigate unstable market and access to financial services. Such lopsided extension delivery approaches also create propensity for askew adoption. Survey and FGD findings revealed that the skewed adoption was due to number of constraining socio-economic arrangements and structure namely; poverty, limited technique skills and subsistence nature of farming systems. The adverse effects of climate change, fragile markets and limited access to agriculture financing as well limited farmers' adoption rate.

On the other hand, basing on the agency-structure theory (Long, 2001; Sewell, 1992), it was evident that smallholder farmers use their agency to make appropriate choices about the variety of digital extension knowledge and practice to adopt. This demonstrated that farmers were knowledgeable about their agricultural information needs. For example, smallholder farmers' adoption of agronomic practices more than others, is engrained within their lived experiences characterized by poor agricultural practices, low and poor yields, deficiencies of indigenous knowledge and socio-economic context. Unlike market information, climate change and financial services that are perceived not to contribute directly to on-farm productivity and production experiences. Thus, smallholder farmers' selective adoption is attributed to the perceived value; which value is within socio-economic context and past experiences, as well as available resources to enable adoption of good agricultural practices. In addition, despite of the digitized extension services, findings show that adoption of market information was still very low. Farmers do not get better prices, there are unstable markets and exploitative tendencies of buyers. Farmers reported that agriculture produce buyers, majority of whom are middle men exploit them through wrong weighing scales as well as low prices and price discrimination. On the hand, the high levels of poverty (monetary pressures) led to side-selling; selling produce to local traders rather than farmer cooperatives and unions. Farmers have enormous monetary pressures and need quick money to settle household needs. On the contrary, another study in Uganda revealed that banana growers realised better prices than maize farmers after getting access to market information through a mobile network (Muto & Yamano, 2011). However, a related study about the poultry farmers' information needs in Kilosa, Tanzania, revealed that most farmers who used "UshauriKilimo" sought information on health management aspects, chicken feeds and feeding, chicken breeds and housing aspects but information on markets was the least used (Msoffe, Chengula, Kipanyula, Mlozi, & Sanga, 2018). Okello *et al* (2012) described the agricultural markets as idiosyncratic market failure coupled with lack of access to market information. This challenge was also underscored by a study on commercial farmers' intention to use mobile phone-based communication technologies for agricultural market information dissemination in Uganda (Engotoit, Kituyi, & Moya, 2016).

Basing on the agency-structure theoretical stance, while the actors make informed decisions after weighing causes of action (King, 2000; Long, 1990, 2001; Sewell, 1992), farmers are entangled in economic structures and rules of market liberalism. The challenge of fragile market and unstable prices is however not new. It is embedded in the neo-liberal policies and rules of engagement, that emphasise a reduction in the government's role in regulating prices and markets to benefit producers, amidst the collapse or weak instrumental farmer cooperatives (MoFPED, 2017). I also argue that even with access to market information, farmers are less empowered to engage in collective bargaining, stick to cooperative principles: collective bulking, bargaining and marketing due to poverty and weak cooperative structures. Hence, the private players especially middlemen are left scout-free to determine market prices with less regard to farmers' interest and expected return on investment. The liberal market structures perpetuate farmers' exploitation. Thus, while digitized extension services have empowered farmers with a wide range of agriculture knowledge and practices, adoption of climate change, market information and financial services is still weak compared to agronomic practices.

3.4 Factors for adoption of mobile phone-based extension services

The last research question addressed by this article was to understand, the motivational factors for farmers to adopt good agricultural practices disseminated through digital platform. It was found out that most farmers are motivated by a number of factors namely; the need to increase on household agriculture production and income (67%), availability of agro-inputs (35%) and influence of fellow farmers (27%). Other motivations for adoption included farmers' desire to strengthen their knowledge and skills, availability of land, influence of VEAs, affordability of materials to use, acquired technical knowledge as revealed in table 2 below.

Table 2: Motivating Factors for Adoption

No	*Motivational Factors*	*Overall*
1	Availability of agro-inputs	**35%**
2	Affordability	**11%**
3	Availability of land	**25%**
4	Technical know-how	**13%**
5	To increase on production & income	**67%**
6	Influence of VEA	**10%**
7	Influence of fellow farmers	**27%**
8	Increase on Knowledge & skills	**25%**

Source: Research data, 2017/2018, *n=390*

In addition to the evidence in table 2 above, matching FGD and key informant interview findings also demonstrate that the most important driver for farmers' adoption of good practices was expected economic gains. Farmers' desire to increase on household agriculture production and income was key incentive to adopt recommended extension practices. For instance, most FGD participants stressed economic motives for adoption of mobile phone-based extension services, a case in question was a female farmer who gave an account that:

Farming is our main livelihood, no body engages in it to work for losses. We were trained in using smart phones, get agronomic information to practice better methods for better yields and income. We are taught farming as a business, and that is what every farmer wants to achieve. We even have a group as VEAs where we share information with others. If you get valuable knowledge which others have not got, then we can be able to share what we learned. We want to be better and support our households ***(Female farmer, Butenga subcounty Bukomansimbi district).***

In addition, key informants affirmed to farmers' claims, underscoring economic gains as the most important driver for adoption:

Farmers look at the cost against output, for example, if you tell me to plant maize two by two and a half (spacing) in a certain area and then I get the same yield with someone who never even wasted time to do the same. The farmer will go and look at the cost of making line spacing, early weeding and such practices. So they look at what cost they incur in relation to output. That is what we call cost benefit analysis. Farmers do a cost benefit analysis in their own way and they are able to know the returns. In addition, farmers are driven by price e.g good price in previous season attracts farmer to invest in that crop ***(Masaka District Agriculture Officer)****.*

In the above narratives, generally, farmers were mainly driven by utilitarian economic reasons. I assert that usefulness of extension services is embedded in expected economic returns for the end users, hence a driver for adoption. Households behavioural change to adopt good agricultural practices is determined by the confidence that the practices have better economic outcomes than what farmers have previously practiced. My findings reverberate with the argument that farmers use mobile communication technologies due to the greater performance such technology offers in their daily transactions (Engotoit et al., 2016). In essence, far from timely information dissemination of mobile extension as in the case with Napalese rural farmers (Devkota & Phuyal, 2018), adoption is entrenched in the expected economic benefits. This is true because economic returns give resources and strengthen capability sets for farmers to achieve the desired personal and household wellbeing. On the other hand, using the agency-structure theoretical concept of duality (King, 2000; Sewell, 1992), I assert that economic motives for adoption is also embedded within the capitalistic structures and rule of the game. The agency of the farmer is exercised within the context of capitalistic economic structures that focus more on profitability and economic gains and not otherwise. Economic motivate for adoption however are complemented by other drivers such as curiosity of farmers to prove whether the information received works, availability of land, agro-inputs, influence of VEAs, farmers' drive to continuous learning through pragmatic farmer field schools and demonstration sites among others.

Worthy mentioning, the influence of social networks was also reported as a driver for adoption. Influence of social networks of farmer to farmer (27%) and farmer to VEA (10%) was an incentive for adoption of mobile phone-based extension. Farmers' social ties and nodes were not only forms of identity and belonging, but also channels of communication, diffusion of mobile phone-based agricultural extension services and drivers of adoption. Farmers with the support of VEAs meet in groups, sharing information, exchange knowledge and benefits through peer to peer social learning. In addition, the influence of social networks on adoption was expressed by most farmers during FGDs. For instance, a FGD participant alluded that:

*Group membership has helped us a lot; we keep visiting each other's farm and check on the implementation of the good practices, we advise each other accordingly. We also ask the VEAs whatever we did not understand and what we forgot. The VEA reaches on the site and helps me to do the right thing for example pruning, digging trenches, fertiliser application and planting good seeds etc (**Female farmer, Butenga subcounty, Bukomansi district).***

Likewise, another participant explains the influence of group solidarity in facilitating adoption of good agricultural practices:
*…need to put a difference between those farmers who are in groups and also those who are not. We always want those other farmers (not in groups) to admire and see the value of being in groups. There is a time we were taught how to stamp coffee plants, but when I went back home and did it, some neighbours who were not in our group said that I had got a lot of money which has influence me cut down the coffee plantations. Little did he know I was simply putting in practise the good agronomic practices. The VEA gave us an example that someone who is having three hundred plants of coffee which are near each other (poorly spaced) and not well managed may get little output compared to someone who manages well the coffee gardens. Our coffee had grown older and they were not yielding much so we were taught to cut them down, so when we did it people laughed and never knew what we were doing. But now they are admiring the plants because they look very health (**Male Farmers, Lwanda Farmer's Cooperative Society Rakai district).***

In this case, the social influence of VEAs, farmer groups and cooperatives enhanced peer to peer learning. Farmers have a reference group influence in form of social pressure that yield people to perform a particular behaviour which would have not been the case if the actors live in isolations without significant others. Adoption is not only influenced by individual's perspective, but also influence of reference groups and collectivities (Durkheim, Simpson, & Spaulding, 1952; Giddens, 1984). In addition, previous studies have suggested that social networks aid social learning and information diffusion with ease; at no cost and information is likely to be given a higher value if it comes from trusted people (Katungi, Edmeades, & Smale, 2008). Likewise, the significance of social networks as a driver for adoption of innovations and extension information is underscored (Martin & Abbott, 2010; Thuo et al., 2014). Hence, mobile phone-based extension through fellow farmers and VEAs characterised by regular and intense interaction; pragmatic skills development techniques and low cost information created more propensity for adoption of good agricultural practices. On the other hand, non-adopters are less socially connected (Warren, 2002). Nonetheless, farmer groups and networks were found to be unique with variations in strength and weaknesses, group attributes; location, gender and agriculture enterprises engaged in. The power of social network is described as social influence: the prediction of the users' intention to use technology based on perceptions of the significant others' thoughts about the individual performing a specific behaviour (Venkatesh & Davis, 2000; Verma & Sinha, 2018). Social influence drives adoption because farmers trust each other more, are able to relate freely and make a livelihood under similar socio-economic conditions. Farmers also believe that their fortunes will improve if they adopted just like the other farmers who have benefited. To note however, although social networks were vital in driving adoption, they are not absolute. Social networks should be understood within the existing social arrangements; with constraints of inequalities, limited resources and varying power relations that could as well constrain the farmers' agency and capacity for effective adoption of good practices.

Despite the novelty of digitisation of agriculture extension services, findings revealed that non-adoption was attributed to the factors related to inadequate resources: limited capital and some techniques are not applicable in the socio-economic context with limited investment capital. In addition, some farmers also reported adverse effects of climate change characterised by erratic rains and long drought spells, poor attitude or mind-set towards recommended agriculture practices, limited and expensive labour and agriculture financing as deterrents for adoption. Whether farmers access and use digitised or traditional extension approaches, these challenges cut-across and hamper the adoption of good agricultural practices at the farmer level.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The study was guided by three main research questions: what kind of information is digitized on a mobile phone-based platform? Which extension services are adopted by smallholder farmers? Lastly, what are the motivational factors for farmers to adopt good agricultural practices disseminated through digital platform? I therefore conclude that smallholder farmers have complex, insatiable and ever changing extension needs based on fused agricultural enterprises. To address these extension needs, knowledge and practices in agronomy, climate change, market information and financial services were digitized on *Kulima* mobile platform. VEAs as community extension agents use *Kulima* mobile phone-based extension platform to support fellow farmers within their radius through social networks of farmer groups. The digitised extension services are built on the VEAs and farmers agency-structure relationship. The duality of such a relationship depend on the farmers' resources, extension agents' accessibility and proximity to the farmers, farmer group structures; embedded in collective social rules and strong ties. However, unlike the traditional extension approach, digitized extension services are still limited in scope and content package; only covering crop farming, with no content on livestock, fisheries among other value chains. The disproportionate digitised extension information does not address all the extension needs of farmers. In essence, digitized extension services in the current form cannot be an independent alternative approach, rather are blended with traditional extension approaches. Intensive research and modifications in digitised extension service is required to ensure comprehensive agricultural content package on a wide range of enterprises; tailored to farmers' extension gaps.

Smallholder farmers leverage their agency to choose the perceived appropriate practices to adopt or not to adopt, with majority adopting agronomic practices that are perceived to directly enhance their production and productivity. Farmers consider agronomic practices to have more direct contribution to their production as economic value more than climate change, market information, and financial services among others. This does not negate the fact that apart from agronomy, agricultural practices are equally important and affect the farmers directly and indirectly. Results show that low cost information and expected economic gains were the main drivers for adoption of mobile phone-based extension services. Intense interaction of farmers with extension agents, pragmatic skills development techniques and social influence of extension agent to farmer, and farmers' social networks also swayed adoption. Smallholder farmers leverage their knowledge, skills and capacity to make decisions about the variety of good agriculture practices to adopt or not, its potential value: things of values to an individual farmer to enhance their agriculture production and welfare. Thus, farmers' behavioural change to use good agricultural practices is dependent on their attitude, perceived benefits, ease of use and usefulness of the practices than what they have been using previously.

However, amidst the desire to adopt digitized practices, smallholder famers encounter structural challenges: economic, environmental, technological and technical know-how. Thus, to strengthen adoption, personal resources, social networks, a web of community extension agents, producer organisations should be strengthened as vital resources, channels of dissemination and adoption of mobile phone-based good agricultural practices. Besides, government in partnership with both private sector and civil society organisations should strengthen and scale-up of the network of VEAs and other lay extension workers to support many agrarian households. The VEA network empowered with mobile phone-based application, and blended with appropriate traditional extension techniques to drive diffusion of new agriculture innovation, ensure effective adoption, and support supervision: on-spot checks, mentorship of farmers, and report on emergencies for swift interventions.

5.0 ACKNOWLEDGEMENT

I am grateful to the Makerere University-Sweden Bilateral Research Program (MAK-SIDA Program) 2015/2016 Project 313-2014, with funding from Swedish International Development Agency (SIDA) whose support enabled me to conduct this study. Secondly, I appreciate my doctoral supervisors: Prof. Andrew Ellias State and Prof. Julius Omona at Makerere University, Uganda, and Dr. Birgitta Jansson at the Department of Social work, University of Gothenburg, Sweden for your mentorship, guidance and comments on the article.

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Vol 4, 2019 Issue, ISSN 2001-2837, Pages 1-89

Next-Generation Wireless Networks for Uganda by 2025

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ABSTRACT

Next-generation wireless networks entail a high degree of flexibility, efficient use of available radio resources and an energy-efficient operation at low operational costs. They typically integrate use of technologies such as spectrum management, interference mitigation and management, and energy efficient technologies. This paper projects the next generation wireless networks scenario of Uganda by 2025, when 5G connections are expected to have crossed the 1 billion mark globally. It builds upon an earlier scenario for Uganda's traffic profile by 2020 that focused on 3G and beyond. The paper identifies major environmental constraints that current and future network architectures will face, in particular deployment density and throughput requirements by 2025, when 5G networks are expected to be commercially available globally. Given the nature of investment required and the need for appropriate policy direction, it is important to map out Uganda's communications scenario for 2025. The paper compares the current and forecast traffic patterns of an urban area (Kampala District) and a fast-growing rural area (Gulu District). The wireless traffic model adopted forecasts throughput requirements as an aggregation of individual service requirements, service usage and user behavior. This paper focuses on voice, mobile Internet and video that are currently among the highly utilized services in Uganda. In similar studies for developed countries, next generation radio access networks are expected to deliver twenty times more throughput and capacity than current 4G/LTE networks while core networks are expected to handle a projected 1,000 times throughput increase, with a more flexible design that can cope with unpredictable demands more intelligently. The analysis for Uganda in 2025 reveals a more modest traffic growth. To meet future requirements with Uganda being largely rural by classification, there is need to stimulate demand and to foster public-private partnerships in addition to innovative spectrum management and efficient energy management.

Keywords: 5G, Capacity, LTE, Next-generation wireless networks, Traffic forecasting

1.0 INTRODUCTION

Since liberalization of the telecommunications sector, Uganda has witnessed remarkable growth in the sector. By 2015, the information and communication technology (ICT) sector was contributing 2.5% share of the GDP with direct employment of 1 million people (MoICT&NG, 2018). It was further estimated that over 1 million people, particularly youth, were also employed in ICT-related activities such as resale of value-added services and in ICT hubs. Nevertheless, opportunity for growth abounds as Uganda still remains below the average for Sub-Saharan Africa. The GSM Association (GSMA) reported that by 2011, the mobile telecommunication sector was associated with 4.4% of the Gross Domestic Product

(GDP) of Sub-Saharan Africa (GSMA and Deloitte, 2012). It had also created more than 3.5 million full-time equivalent jobs across both the formal and informal sectors.

Globally, the growth of demand in the telecommunication sector was expected to continue to grow even up to 2020, although at slightly slowing pace (Blume *et al..*, 2013). For instance, studies conducted in developed countries showed exponential growth and a 1,000-fold improvement in 2020 traffic compared to a 2010 reference (Blume *et al.*, 2013, Gelabet *et al.*, 2013, Zander *et al.*, 2013). It was also expected that second generation (2G) and third generation (3G) wireless networks would be replaced by fourth generation (4G) and beyond-4G networks (Blume *et al.*, 2013, Mogensen *et al.*, 2012). In terms of services, growth was expected in five major categories, web, video, peer-to-peer, wireless data and wireless voice (Kilper *et al.*, 2011). These services represented only a fraction of the then available or future services. In general, wireless and mobile Internet access were expected to emerge as a dominant technology in which wireless access would be abundant and virtually free (Zander *et al.*, 2013).

Statistics from Uganda Communications Commission (UCC) reveal an increase in internet penetration which is largely driven by a growth of mobile internet subscription (UCC, 2018). The percentage of individuals using the internet has grown from 0.2 per cent in 2000 to 24 per cent by year end 2017 (ITU, 2018a). This growth is attributed, in part, to the growing popularity and usage of smart phones in Uganda as well as a growth in demand for 3G/4G/LTE services and beyond. Such growth does need to address constraints including access to spectrum, sector-specific taxes on mobile terminals and usage, standardized rights of way due to significant investments required, and a collaborative public-private partnership approach to the sector's development (GSMA and Deloitte, 2012). Indeed, a review of the Uganda National Broadband Policy of 2018 has key principles that include open and universal access to broadband infrastructure, cross-sector infrastructure sharing including a "dig-once" approach to cater for all public utilities, a right mix of technology and network neutrality, and environmental consideration (MoICT&NG, 2018). In general, next-generation wireless networks entail a high degree of flexibility, efficient use of available radio resources and an energy-efficient operation at low operational costs (ITU, 2018). They typically integrate use of technologies such as spectrum refarming/aggregation, cognitive radio/software defined radio, beam forming and distributed multiple-input multiple-output (MIMO) antenna systems, interference mitigation and management, cooperative radio resource management, and energy efficient technologies.

2.0 THE CASE FOR 5G NETWORKS

Beyond 4G, trials for 5G networks are underway in a number of countries (ITU, 2018). 5G networks are expected to have significant broadband capacity, with download speeds of at least 100 Mbps, to support massive machine-to-machine communications as well as to provide low-latency, high-reliability service for time critical applications (ITU, 2018, Nguyen *et al.*, 2017). This will require deployment of innovative technologies including software defined networks (SDNs), network virtualization, and info-centric networking to make 5G networks faster, smarter and more cost-effective.

In addition to capacity constraints, 5G will require much more spectrally efficient technologies and spectrum allocations beyond what is in use for 3G and 4G networks. 5G is projected to use frequencies above 24 GHz which poses two additional challenges (ITU, 2018). Firstly, radio propagation at such frequencies is known to be very suspect to weather, in particular, rain – itself a common feature in tropical countries such as Uganda. Secondly, frequency bands above 24 GHz are already in use by various services such as satellite communications, weather forecasting, and monitoring of earth resources and climate change. Hence the need for regulatory policies that provide an enabling environment to attract investment in the development of virtualized, highly configurable and elastic networks to deliver 5G services in Uganda (O'Briain *et al.*, 2017).

In terms of penetration, the GSMA estimates 5G connections to reach 1.1 billion by 2025, and that this will represent 12 per cent of the total mobile connections (ITU, 2018). Since 2012, the International Telecommunication Union has been developing the international mobile telecommunication (IMT) standards for 5G (IMT-2020). The first commercial deployments are expected by 2020. Countries considering 5G services will do well to assess the value of different use cases proposed for 5G. These use cases include sharing of any type of content anytime, anywhere and through any device; easy access to digital textbooks or cloud-based storage of knowledge on the Internet; energy efficiency by supporting massive machine-to-machine communications and solutions such as smart grid, teleconferencing, and smart logistics and transportation; and broadband mobile service delivery and information exchange where broadband connectivity is treated with the same priority as access to electricity (ITU, 2018). It should be noted that the National Broadband Policy already calls for broadband infrastructure to be defined and planned for like any other public good such as roads, railways, oil pipeline, and power lines (MoICT&NG, 2018).

This paper aims to project the next generation wireless networks scenario of Uganda by 2025 when 5G connections are expected to have crossed the 1 billion mark globally. It builds upon an earlier scenario for Uganda's traffic profile by 2020 that focused on 3G and beyond (Okello *et al.*, 2015). The paper identifies major environmental constraints that current and future network architectures will face, in particular, with respect to deployment density and throughput requirements by year-end 2015 over a ten-year period to that forecast for 2025. The focus is on three services, namely, voice, mobile Internet and video that are currently among the highly utilized services among Ugandan mobile subscribers, and that are expected to have increasing throughput requirements over the period to 2025. The paper further compares the current and forecast traffic patterns of an urban and a rural area in Uganda.

3.0 TRAFFIC PROFILE IN UGANDA

Given the nature of investment required and the need for appropriate policy direction, it is important to map out Uganda's communications scenario for 2025. This includes analysis and specification of traffic requirements, the development and integration of new technical solutions, and the dissemination of results to ensure the required impact (Osseiran *et al.*, 2013). The focus of this paper is on the analysis and specification of Uganda's traffic requirements.

While one can assume that there will be traffic growth across the country, the rate is certain to differ between urban and rural areas. The urban-rural dimension is also important as operator intervention may be limited in rural areas due to poor returns on investment. For purposes of this work, Kampala District was selected as an urban area since it has a population density of over 1,000 persons/km^2, and Gulu District was selected as a rural area since it has a population density of under 300 persons/km^2 (Blume *et al.*, 2013). Gulu District is also considered a fast-growing area of interest for the telecommunication sector since Gulu Municipality is among the top ten most populated municipals and towns in Uganda. These two districts were also the basis for the 2020 scenario study (Okello *et al.*, 2015). Table 1 presents a demographic profile of the two districts. It is assumed that the district land area remains the same over the period 2015 – 2025. The statistics for 2015 and the estimates for 2025 population statistics for Kampala, Gulu and Uganda are obtained from the Uganda Bureau of Statistics.

Table 1: Demographic profile of Kampala and Gulu Districts

	Area (km^2)	Population (2015)	Pop. density (2015, pop/km^2)	Population (2025, est.)	Pop. density (2025, pop/km^2)
Kampala	839	1,529,400	1,823	1,819,700	2,169
Gulu	3,449.08	282,000	82	370,300	107
Uganda	241,550.7	35,502,100	147	48,317,300	200

Source: Uganda Bureau of Standards (UBOS, 2019)

Typical of many Sub-Saharan African countries, Uganda's telecommunications needs are largely served by wireless and mobile networks (UCC, 2018). Furthermore, given the higher population density, it not surprising that the higher speeds of up to 21 Mbps are only available around Kampala (UCC, 2013).

4.0 ASSESSING UGANDA'S TRAFFIC REQUIREMENTS BY 2025

This paper focuses on Uganda's traffic requirements by 2025, particularly the throughput requirements. The throughput or data rate required for various services will in turn affect the technical solutions for provision of connectivity including the spectrum requirements. The projections are important to guide the growth mix requirement in infrastructure and policy to guide the path to the next generation wireless networks.

At the outset, it is important to acknowledge the difficulty in predicting capacity demands – more so, since different forecast studies provide varying results (Gelabert *et al.*, 2013). Nevertheless, for planning purposes, it is important to generate information on likely requirements. Secondly, as previously mentioned, a number of the traffic forecasts project exponential growth up to the order of 1,000 times growth. However, these forecasts are based on subscription and services trends in developed countries and may not be directly utilized for in the context of a developing country. Examples of these models include the GreenTouch framework applied in the most mature markets of North America, Western Europe and Japan (Blume *et al.*, 2013, Gelabert *et al.*, 2013); and use of historical, annual U.S. and global compound annual growth rates for traffic reported by a number of large carriers and industry analysts (Kilper *et al.*, 2011). Indeed the 2020 traffic forecast has been shown by today's trends to have about double the 25,211,164 subscribers by year-end 2017 (ITU, 2018a; Okello *et al.*, 2015).

For this work, the wireless traffic model used is by the Wireless World Research Forum (WWRF). This model is able to account for several demographic scenarios and user capacity estimates (Wu, J. *et al.*, 2011). The model accounts for the following environmental constraints: population density, penetration rates, user/subscriber density, energy constraints, and the regulatory environment. The WWRF model results tend to a conservative maximum ceiling since the model does not account for indoor/outdoor traffic as well as combined wireless/wired infrastructure (Gelabert *et al.*, 2013). Furthermore, in this work, the traffic requirements are estimated taking into account only population density, penetration rates, user/subscriber density and regulatory aspects. The user/subscriber density is obtained as a product of the population density and the penetration rates. Depending on the age structure of a population and the population aged above 15, there could be a saturation of penetration rates due to the actual number of wireless users/subscribers. With a very young population, even with a drop from 48 percent in 2015 to 43 percent in 2025 of those below the age of 15 (UBOS, 2019), the age structure is an important consideration for Uganda. Other factors that could affect saturation of penetration rates are literacy rates as well as accessibility and affordability of wireless services.

To assess the penetration rates over the period up to 2025, there is need to apply an appropriate trend for Uganda's traffic growth. Figure 1 compares different trend lines explored in the scenario 2020 study to estimate Uganda's traffic growth based on subscriber growth from 2000 – 2013 (Okello *et al.*, 2015).

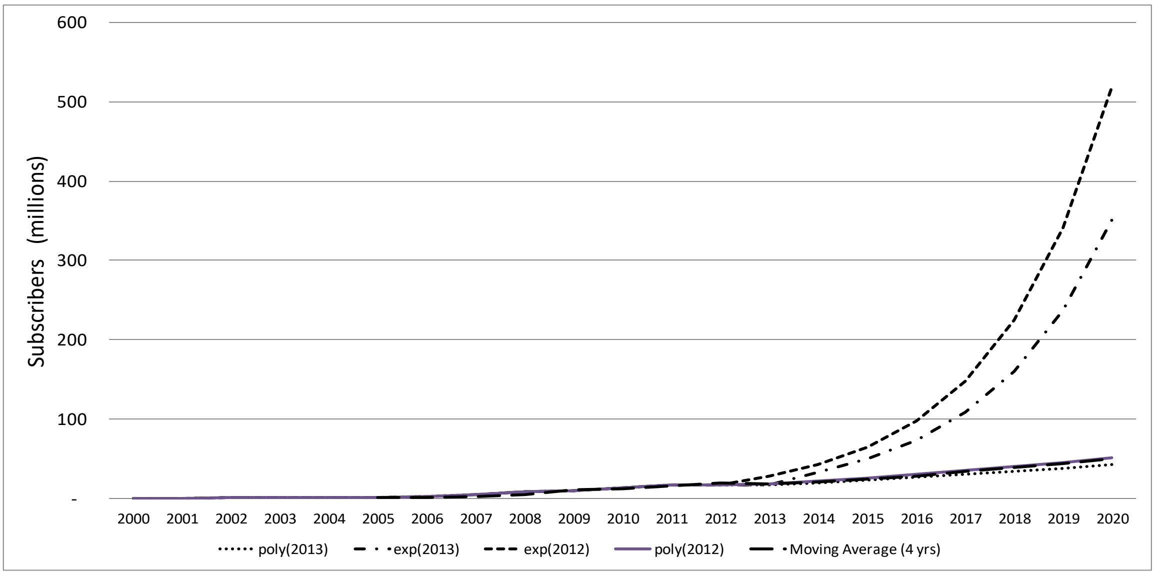

Figure 1: Possible trends of Uganda's subscriber growth up to 2020

Figure 1 compares different exponential and polynomial growth trend lines explored to estimate a best fit line to Uganda's traffic growth. While developed countries were considered to have exponential traffic growth (Blume, 2013), Figure 1 revealed that an exponential subscriber growth trend would result in unrealistic predictions for Uganda's subscribers by 2020. This is because it would mean that Uganda would achieve penetration saturation by 2014. Thus, a polynomial growth trend was selected to represent the trend of Uganda's subscriber growth, which in turn yielded the penetration rates of 0.48 and 0.95 in 2012 and 2020 respectively that were used in the 2020 study. However, these penetration rates are observed to have nearly doubled the estimate of Uganda's subscribers in 2020 relative to current statistics (UCC, 2018). For the scenario 2025 study, it is thus proposed to assume a conservative estimate of half the growth in penetration rate used for the year 2020. The user densities for the two regions under study are then obtained as highlighted in Table 2. A user density of at least 1,000 and 300 people per unit area (km) is required for classification of urban and suburban, respectively, with respect to telecommunications demand (Blume *et.al.*, 2013)

Table 2: User densities for Kampala District, Gulu District and Uganda

		Population Density (people/km^2)	User Density (people/km^2)	Classification
Kampala	2015	1,823	866	Suburban
	2025	2,169	1,030	Urban
Gulu	2015	82	39	Rural
	2025	107	51	Rural
Uganda	2015	147	70	Rural
	2025	200	95	Rural

Throughput Requirements for 2025

Throughput requirements for services per user, *T(s)*, introduced by a wireless service, *s*, may be estimated as a function of the bit rate requirement of each service, service usage rates, and user behavior according to the WWRF traffic model (Wu, J. *et al.*, 2011). Equation 1 estimates the throughput requirements for a user with multiple services.

$$T_{user} = \sum_{s=1}^{S} T(s) = \sum_{s=1}^{S} P_u(s)P_t(s)R(s) \tag{1}$$

where $P_u(s)$ is the percentage of users using service *s*, $P_t(s)$ is the probability that service *s* is used by wireless devices of a user at a given time and is a function of user behavior statistics and busy hour statistics, and *R(s)* is the bit rate required to deliver service *s* such as voice, data, video, etc.

While there are models that estimate the busy hour traffic by activity for mature markets such as Europe, no such models are in place for developing countries such as Uganda. Secondly, even for developed countries, it was very difficult to estimate $P_u(s)$, $P_t(s)$ and *R(s)* for all services in 2020 and this remains a challenge even for 2025. This is primarily because service statistics and user behavior are difficult to predict. To overcome the challenge for developing country predictions, the use of total traffic estimates per user has been proposed (Wu, 2011). These estimates can then be used to determine the throughput requirement per area, T_{area} – where T_{area} may be estimated as a product of the user density and throughput requirements per user.

To estimate Uganda's requirements, we use estimates reported by the Program for Infrastructure Development in Africa (PIDA, 2011). By 2018, it was expected that at least 10% of the population has high speed access, that 20 to 30% of the population has ready access to internet. For this study, we retain the same probabilities of access to the internet. For high speed access, we consider the average rates as proposed in the Uganda National Broadband Policy. Uganda's National Development Plan has envisaged broadband access speeds of 30 Mbps per household in urban areas, and the Broadband Policy requires at least 4 Mbps across the country (MoICT&NG, 2018). Table 3 presents the throughput requirements for Kampala and Gulu Districts based on application of the WWRF traffic model in which the use of total traffic estimates per user is applied.

Table 3: Throughput requirements for Kampala and Gulu Districts by 2025

	2025 (Mbps/km^2)	2025 (Mbps per capita)
	10% high speed (30 Mbps, Kampala), 30% good internet (4 Mbps)	
Kampala	4,120	2
Gulu	61.2	0.6

The 2025 results presented in Table 3 reveal significant requirements for Kampala relative to the requirements of Gulu. Furthermore, the throughput requirements were compared with those obtained by the PIDA study which forecast Uganda's bandwidth requirements by 2018 at about 600 Gbps (PIDA, 2011). It is observed that the 2025 requirement for Kampala exceeds the PIDA projection of 600 Gbps, while that for Gulu is below. This is not surprising as Kampala being a key urban centre would dominate the throughput requirements. However, it should be noted that forecasting based on extrapolation is typically problematic, and hence a limitation for this study. It is thus important to acknowledge that the results presented in this paper are indicative of the expected magnitudes of throughput required and are therefore treated as only estimates.

5.0 ANALYSIS OF RESULTS

Using Kampala and Gulu as samples of throughput requirements in Uganda, Table 2 shows a transition from sub-urban to urban status for Kampala while Gulu remains with a rural status with respect to telecommunications demand from 2015 to 2025. Still, there remains need for development of Uganda's national broadband infrastructure since even rural areas of Uganda will have increasing need for high-speed services. As reported in the National Broadband Policy, by September 2018, Uganda already had 45 percent 3G coverage. Secondly, the results obtained further point to two additional constraints that need to be addressed regulatory aspects and energy constraints. Increasing spread of infrastructure will have increasing energy requirements with wireless networks consuming up to 80% of the energy required for communication networks (Blume *et al.*, 2011, Kilper *et al.*, 2011, Zander *et al.*, 2013). While this study has focused on throughput requirements, it is important that further work take regulatory and energy constraints into consideration.

Furthermore, a key assessment for 5G services is available business cases for its deployment. While the National Broadband Policy calls for 4 Mbps across the country and the 4G and 5G standards provide for download speeds of 100 Mbps or more to be available on demand, the 2025 forecast shows a per capita requirement in Kampala of 2 Mbps. 5G tests show connection densities of 1 million devices/km^2 (Morgado *et. al.*, 2018) typically which may only occasionally be needed in Kampala for large events or high density of sensor networks. On the other hand, while 4G might not support dense deployments at massive industrial scale internet of things (IoT), it can support 2,000 connected devices/km^2 (Javaid *et. al.*, 2018) which can well serve the needs for Kampala. This means that adoption of 5G will require well considered business cases for its deployment. Today, a viable case can be made for 5G in densely populated urban areas (ITU, 2018). Viable use cases include high-speed mobile broadband to crowded areas, high-speed streaming for in-home services on demand, enterprise collaboration services, smart cities and IoT through massive deployment of low-power sensor networks in cities and in rural areas, low-latency applications such as remote surgery, factor automation and control of real-time processes, and last mile solutions in areas without fibre to the home connections or network backhaul solutions. 5G deployment in

Uganda will therefore require an assessment for demand and/or a robust commercial case. Furthermore, this means that there is still need to retain the availability and quality of 4G networks as a viable broadband option as the case for 5G matures. There is also need for stimulation of nationwide deployment of fibre networks as well as affordable wireless networks so as to minimize the risk of increasing the digital divide arising from selected deployments of 5G networks. While the forecast in this study is focused on wireless networks, the National Broadband Policy requires that networks consider an appropriate mix of technologies to ensure efficient and complementary broadband infrastructure deployment nationwide. This means that an appropriate mix of wireless and wired/fiber options will need to be considered thus minimizing a risk that the digital divide in Uganda would increase because 5G networks were being prioritized over fiber networks, for example. The consideration of an appropriate mix is important since adoption of 5G is currently considered a viable option for densely populated urban areas whereas Uganda is largely rural as highlighted in Table 2.

In addition to the business case, a primary regulatory aspect is availability of spectrum to support increasing throughput requirements via wireless networks. For instance, of the five spectrum bands identified for 4G/LTE, the uplink spectrum range lies with the digital dividend expected to result from the digital migration process. However, while frequency re-allocation and dynamic spectrum access may provide rapid market entry possibilities, they will not be sufficient to make available the necessary spectrum for increasing throughput requirements (Zander *et al.*, 2013). There will also be need for techniques and enablers for innovative spectrum sharing and flexible spectrum management (Osseiran *et al.*, 2013).

As was the case for the 2020 study, another regulatory aspect to be addressed is multi-stakeholder collaboration through public-private partnerships, for example, to spur both rollout of infrastructure and motivation of demand for the infrastructure (Okello *et al.*, 2015). In terms of user density, Uganda is largely classified as a rural scenario and hence the need for innovative approaches to grow the country’s telecommunications infrastructure and its usage.

6.0 CONCLUSION

Remarkable growth in the telecommunication sector is being witnessed in Uganda and beyond. Consequently, new networks are needed to service the growing demand. For Uganda, this growth shall largely be met by wireless networks but should be complemented by a right mix of technology including fibre networks. Future wireless networks could be deployed for future low latency and high reliability but also prevailing backhaul solutions due to high data rates of up to 100 Gbps. The design of Uganda’s next generation wireless networks entails the need to assess future traffic requirements and major environmental constraints. The networks shall also entail a high degree of flexibility, efficient use of available radio resources and an energy-efficient operation at low operational costs.

Analysis of Uganda’s 2025 traffic requirements reveals growth even with much of Uganda being classified as rural with low device/penetration density. Innovative technical and policy interventions will thus be required to support the traffic requirements. This shall include fostering public-private partnerships as well as development of innovative spectrum management techniques coupled with efficient energy management. At the foundation of these interventions is the need for further research focused on the regulatory and environmental constraints typical of developing countries such as Uganda.

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Vol 4, 2019 Issue, ISSN 2001-2837, Pages 1-89

ENERGY EFFICIENT TECHNIQUES FOR NEXT-GENERATION WIRELESS NETWORKS

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ABSTRACT.
A consistent issue of concern in the design of future mobile cellular systems is the energy consumption of the radio access network. The deployment strategy has a huge impact on the overall energy performance of the network. This paper considers a high data rate network using 4G Long Term Evolution technology to evaluate the energy performance of the network given variable base station densities in both urban and rural environments. The paper quantifies the amount of energy savings that can be obtained due to the deployment of different cell sizes in an area with a given user density. It also compares the increase in cost that arises due to the deployment of small cells with the gains that are realized by using small cells. Our results show that there are specific optimal cell radii in rural and urban environments at which the energy performance of the network is maximized. In addition, it is shown that small cells are more suited to urban environments where users can exploit them to enhance network capacity. However, due to their sparse population densities, rural areas require relatively larger cells to maximize energy gains.

Keywords: 4G, 5G, network optimization, energy efficiency

1.0 INTRODUCTION

The issue of energy consumption in cellular networks has attracted significant attention in both industry and academia. This is due to the explosive growth in traffic demand which is driving the need for innovative solutions for mobile broadband services. This drive has led to the evolution from 2G to 4G networks, and now to 5G that promises to deliver improved end-user experiences through gigabit speeds, and improved performance and reliability (ITU, 2018). The volume of transmitted data increases approximately by a factor of 10 every five years, which corresponds to an increase of the associated energy consumption by approximately 16 to 20%. This has led to increased capital expenditure and increased operational costs including the cost of energy. In cellular networks each base station can require up to 2.7kW of electrical power which can lead to an energy consumption of tens of MW per annum for wide area networks. Energy consumption analysis shows that between 50% and 80% of the total energy in a wireless network is consumed in the base stations (Mugume *et al*, 2013, Hasan *et al*, 2011, Badic et al, 2009).

Operators are looking for economical and sustainable solutions to reduce their operational expenditure most especially the cost of energy. Several techniques can be used to reduce network energy consumption such as improved radio base station equipment design, energy-efficient cooling systems or avoiding cooling by using remote radio units (Marsan *et al*, 2009, Chabarek *et al*, 2008, Hodes, 2007, Rinaldi *et al*, 2007).

One technique in particular has both an energy saving component as well as a key service delivery mode, particularly in the case of 5G networks. This is the use of innovative infrastructure sharing. Early 5G deployments are expected to be largely evolutionary to 4G/LTE primarily to support high-bandwidth mobile data in dense urban or suburban areas (GSMA, 2017). For 5G to be a success, policies and regulations that strengthen the viability of 5G networks include innovative spectrum and infrastructure sharing models, dynamic renting of infrastructure and backhaul, and enabling capacity sharing models. Open and universal access to broadband infrastructure as well as infrastructure sharing are also key principles of Uganda’s National Broadband Policy (MoICT&NG, 2018).

Infrastructure sharing and, in particular, the notion of a neutral host provider gains even more prominence as a strategy for cost effective high-speed services. Neutral hosts could be in form of a wireless infrastructure provider that supplies passive mast and tower infrastructure only to neutral host providers that could deploy their own active equipment (DDCMS, 2018). With active equipment, a neutral host may transmit on behalf of mobile network operators (MNO) and mobile virtual network operators either in their own spectrum or the MNOs’ spectrum. As such, neutral hosts can boost energy efficient coverage in various scenarios including (1) dense urban areas where shared networks could be desirable in order to reduce deployment costs including energy requirements, (2) remote rural areas where there could be insufficient demand to justify multiple networks, and (3) in offices and factories where local networks can be deployed to provide coverage and capacity within the building.

A neutral host approach also lends itself well to a key component of 5G networks which is the use of small cells. To deliver on the promise of high-speed connectivity anywhere any time calls for an ecosystem of heterogeneous, multi-access network infrastructure in which small cells play a critical role in three usage scenarios: indoors, outdoors in dense urban areas, and outdoors in economically challenging areas (GSMA, 2017). A proposed spectrum allocation includes a low capacity layer providing wide area 5G coverage using the 700 MHz band, high capacity small cells in areas of high demand using 3.4 – 3.6 GHz band, and in the longer term, even smaller hotspots of very high capacity using mmWave bands in the range of 30 – 300 GHz (DDCMS, 2018). This again raises to the fore a key issue of innovative regulation for spectrum management. It is therefore timely that the regulator is developing a Radio Spectrum Management Policy to guide the efficient and effective radio spectrum management towards the realization of national social economic development (UCC, 2018).

This paper compares energy savings that can be obtained by deployment of small cells in two areas, one urban and one rural. This paper is organized as follows. First the system model used in the simulation is analyzed, followed by the results obtained in the simulation and the observations and conclusions as per the results obtained.

2.0 SYSTEM MODEL

2.1 Case Study

Two areas of 2 square kilometers were studied for a rural and an urban deployment. The areas considered were Kampala, Central Uganda, for the urban area and Kisoro, South Western Uganda, for the rural area. The mean number of users to be served in that area for a given cell radius was determined. Population estimates were based on Uganda Bureau of Statistics 2018 estimates which give a population density of 1,932 and 417 people per square kilometer respectively for Kampala and Kisoro which are of area 839 km^2 and 728 km^2 (UBOS, 2017, UBOS, 2019). For purposes of this work, Kampala District was selected as an urban area since it has a population density of over 1,000 persons/km^2, and Kisoro District was selected as a suburban/rural area since it has a population density of under 1,000 persons/km^2 (Blume *et al.*, 2013). To obtain the mean number of subscribers in the two regions, we assumed that mobile subscriber population is distributed in accordance with the population distribution per country. Using 2018 figures for mobile subscribers nationwide of about 24.5 million subscribers (UCC, 2018a), and assuming an operator with a 52% market share, we obtained the mean user density per square kilometer for the operator at 630 and 135 respectively for the urban and rural areas under consideration for this study.

The number of e-NodeB's that cover the area for the varying cell radius was calculated for the different inter e-NodeB distances, assuming a maximum distance of 2 km for a single e-NodeB. Hexagonal cellular cell deployment was considered in the selected areas. The radius of a cell-site denoted by R is fully adjustable with the inter-site distance = 1.5R for a hexagonal geometry. Base stations are configured with three sector antennas, with directions of 0, 120, and 240 degrees. The area, A_{cell}, that is defined for N cells each of radius R, and the mean cell transmission power P_{cell} per sector are given by (Auer *et al*, 2011):

$$A_{cell} = \frac{R * R * 3\sqrt{3}}{8} \quad (1)$$

$$P_{RAN} = P_{cell} \times N \quad (2)$$

The path loss model considered was the COST 231 Model for path loss in various areas for propagation up to 2 GHz band (Hassan *et al*, 2013):

$$L_p = 46.3 + 33.9 \log f_c - 13.82 \log h_b - a(h_m, f_c) + (44.9 - 6.55 \log h_b) \log d + C \quad (3)$$

where f_c is the frequency of transmission in MHz (between 1500 and 2000 MHz); h_b is effective base station antenna height in meters (between 30 and 200m); h_m is mobile antenna height (between 1 and 10m); $a(.)$ is a mobile station antenna height correction factor in meters for large and medium sized cities; d is in km; C is a correction factor with C = 0 dB in medium and suburban areas, 3dB in urban and metropolitan areas, and -17 dB in rural areas.

To determine the best deployment cell size, the energy efficiency performances of large cells and small cells is evaluated by measuring the energy efficiency performances (e.g. energy consumption ratio, energy consumption gain) achieved for various cell sizes and antenna heights while maintaining the quality of service (for a given cell coverage and mean cell capacity) under a cell transmission power constraint. After comparing the Energy Consumption Ratio (ECR) for each cell size, a suitable system deployment option can then be found in terms of the cell size. Similar calculations are performed for the Energy Consumption Gain (ECG) across the radio access network.

2.2 Power Model

A base station consists of multiple transceivers (TRXs), each of which serves one transmit antenna element. A TRX comprises a power amplifier (PA), a radio frequency (RF) small-signal TRX module, a baseband engine including a receiver (uplink) and transmitter (downlink) section, a DC-DC power supply, an active cooling system, and an AC-DC unit (mains supply) for connection to the electrical power grid. The following power model was used while carrying out these simulations (Auer *et al*, 2011):

$$P_{in} = N_{TRX} \times P_O + \Delta \times P_{OUT}, \; 0 < P_{OUT} \le P_{MAX} \quad (4)$$

P_{OUT} is output power, N_{TRX} is the number of transmit chains, P_0 is the power consumption at the minimum non-zero output power, Δ is the slope of the load-dependent power consumption and P_{MAX} is the output power at maximum load. It should be noted that for this project, sleep mode capability is not investigated. The power savings that are quantified are due to deployment of small size cells.

2.3 Energy Metrics

In the study of energy metrics, the total system wide energy includes embodied energy as well as operational energy for services delivery. The operational energy is a function of the radio access architecture which includes cell size, base station antenna height, antenna radiation pattern, distance of the transmitting and receiving antennas, interference, multipath fading, shadowing, radio resource management, user density, user mobility, and traffic scenarios. Embodied energy is the energy consumed by all processes associated with the production of a device (Humar *et. al*, 2011). It comprises of initial embodied energy that is used to acquire and process raw materials, transport, manufacture components, and assemble and install all products in the initial device construction. It is also comprised of maintenance embodied energy associated with maintaining, repairing, and replacing materials and components of the device throughout its lifetime. For this paper, embodied energy is taken as a fixed component in the energy performance evaluation and the focus is on the operational energy that is known to decrease when sleep-mode or power-down strategies are applied. The primary energy metric used in this paper is the Energy Consumption Gain (ECG). This is the ratio of the power of a RAN for large cell deployment to small cell deployment for a given period of time:

$$\mathrm{ECG} = \frac{\mathrm{P\ (RAN\ LARGE)} * \mathrm{t}}{\mathrm{P\ (RAN\ SMALL)} * \mathrm{t}} \quad (5)$$

ECG can also be obtained by dividing the Energy Consumption Ratio (ECR) of a large cell deployment to that of a small cell deployment. The ECR is an energy performance metric that expresses the energy consumed per delivered bit of information, i.e. ECR = $\frac{\mathrm{E}}{\mathrm{M}}$, where *E* is the energy that is used to deliver *M* bits of information over time *T*.

3.0 RESULTS AND ANALYSIS

Results obtained for this are based on the VIENNA LTE level network simulator that was developed in MATLAB. System parameters and simulation assumptions are chosen to comply with known LTE standards. Some of the main parameters used in the simulation are shown in Table 1 and are based on a similar study undertaken for Kampala and Kisoro (Okello *et al*, 2015). The cost of the different cell sizes was computed based on a Nokia flexi e-NodeB that supports up to 250 active users/devices simultaneously.

Table 3: Simulation Parameters

Name	Parameter
Frequency	2 GHz
Bandwidth	5 MHz
Propagation model	COST 231 HATA
Transmitter height	20 m
Receiver height	1.5 m

The plot in Figure 1 is the total power consumed in the considered area against the different cell sizes for both rural and urban areas. This plot shows that the power consumed decreases as cell size reduces to a radius of about 350m for the urban area and 1,000m for the rural area. Below these two radii, power consumed increases for the respective areas. This is because deploying a small cell size in the same area would entail using very many of them for a given user density. Though these would be transmitting at lower power values, their total fixed power increases linearly. As the number of small base stations increases further, there is a point beyond which the overall power consumption begins to increase.

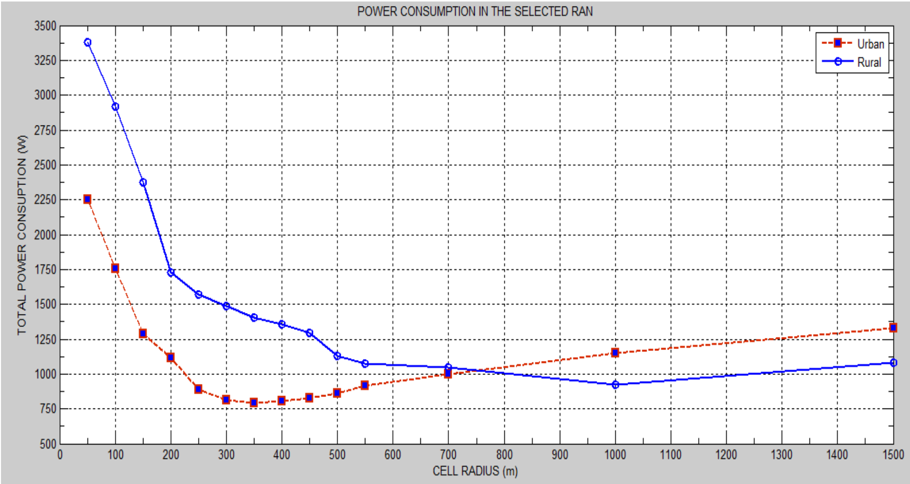

Figure 1: Total power consumption vs Cell radius

Figure 2 shows the percentage power savings and cost increase for both urban and rural areas. Power savings are achieved for urban areas as compared to the rural environment up to a cell radius of about 200m. The costs are based on the total number of base stations required to cater for users within a given radius. It is assumed that a base station can meet the traffic requirements for up to 250 active users simultaneously. It is observed that the percentage increase in cost for small cells is relatively narrow as compared to large cells.

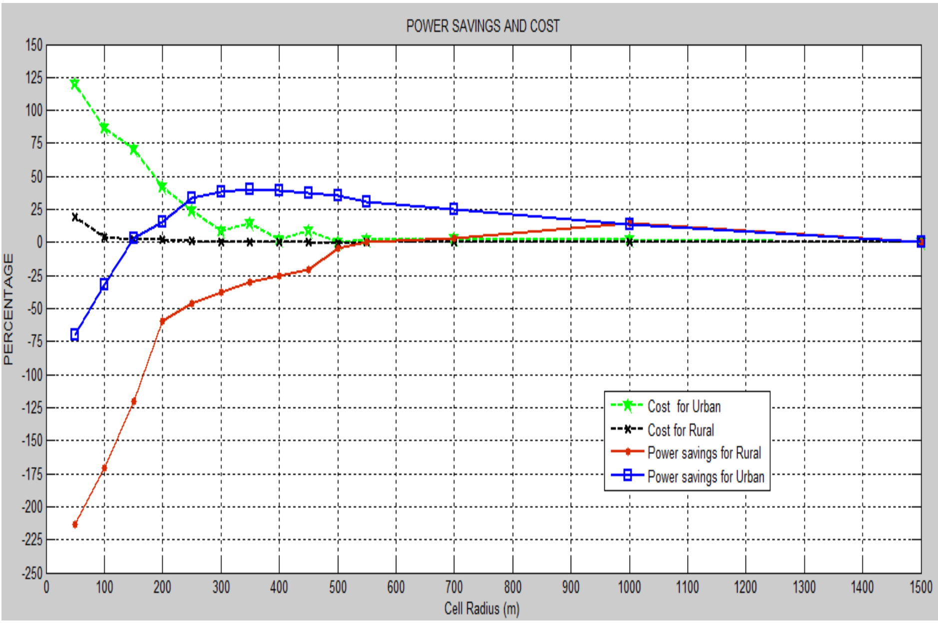

Figure 2: Percentage power savings and cost vs Cell radius

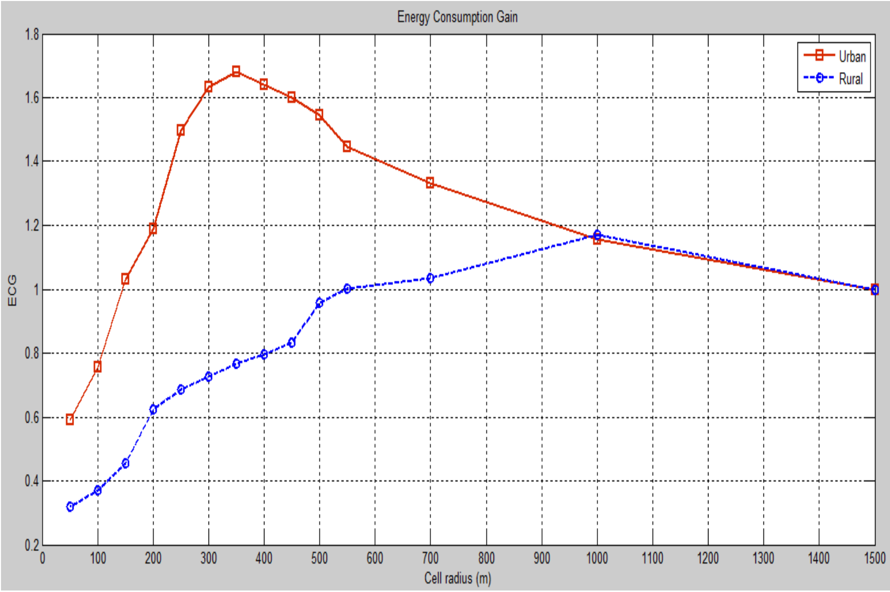

Figure 3: Energy Consumption Gain vs Cell radius

Figure 3 shows that with smaller cell sizes, an ECG greater than 1 is obtained for the urban environment over a wider cell radius variation. Note that ECG for the rural area is below 1 for small cell sizes. Therefore, from an energy efficiency perspective, small cells are more efficient to deploy in the urban areas as compared to rural areas.

4.0 CONCLUSION

In this paper, the effect of reducing the cell size was investigated in a 4G/LTE mobile network as an evolutionary path for 5G networks. Networks in Uganda are using both the 700 MHz range and the 2 GHz range for provision of LTE services, and hence the results are a good indicator for energy efficiency for 4G networks and beyond. The study has shown how percentage power savings reduced with decreasing cell sizes in the two regions considered, but up to a point. For instance, energy consumption gain reduces significantly below a cell radius of about 300m for an urban deployment. Even then, it is observed using energy consumption gain that deployment of smaller cells in the urban areas is more efficient than in the rural areas. Hence in addition to a critical examination of the business case for high-speed 5G networks in rural areas, there is need to promote broadband access strategies for rural areas that are both energy efficient and an appropriate technology mix of perhaps 3G/4G networks. In this way, national ICT development can progress without a widening digital divide.

Small cells are the preferred delivery mechanism for 5G given their ability to deliver on dense coverage, low latency and high bandwidth requirements (ITU, 2018). Furthermore, small cells can deliver on the anticipated high-speed capacity without the need for additional spectrum due to their enhanced frequency reuse capability. However, as shown, energy consumption gain for small cells drops for radii below 300m and 1,000m in the two regions under consideration. This means that careful balancing of the high-speed access versus energy requirements will be necessary as small cells, more so in 5G networks that are expected to go even much lower than the optimal 300m radius obtained in this work.

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Design and Development of an Interactive Analog and Digital Filters Characterization Laboratory Based on LabVIEW

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ABSTRACT

Remote labs, also known as iLabs are increasingly being preferred over the conventional physical labs to enhance learning in engineering disciplines. They allow the simultaneous sharing of expensive laboratory equipments between students and universities online. In this research, an iLab that characterises analog and digital filters was designed on the LabVIEW platform. It covers; filtering concepts of both analog and digital filters as well as stability of filters. Low-pass, high-pass, band-pass, and band stop analog filter circuits were designed using Multism Circuit Design Suite V13.0, then implemented on the NI ELVIS II prototyping board powered by LabVIEW software using LM 741 Op-Amps, relay circuits for switching between different outputs for analog filters, capacitors, and resistors. The NI ELVISmx Digital Write express Virtual Instrument was used to control the relays connected at different output pins of the analog filters and to remotely switch between the filter types over the local network. The NI ELVISmx Analog Write express Virtual Instrument was used to read analog signals from the output pins of the filter circuits into the user interface. Digital FIR and IIR filters were designed and developed using the LabVIEW 2013 software package together with the LabVIEW Digital Signal Processing module. An intuitive user interface was designed to provide the means for launching, monitoring, controlling, and reading results from the laboratory hardware equipment and the digital filters. A learner can access the lab through a web link which runs on the iLabs Shared Architecture, select an experiment of interest, gain control of the laboratory hardware equipment, set experiment parameters and obtains results in real time.

Keywords: Analog filters, Digital filters, Signal Processing.

1.0 INTRODUCTION

1.1 Background

Innovations in the field of experimentation in engineering have greatly changed methods of delivering knowledge to learners. Pedagogical techniques are changing from the traditional “chalk and talk” sessions to “application-orientation” or “workshop/laboratory-based” approaches so as to reinforce theoretical concepts [1]. Some of these approaches have been designed to provide students and researchers with experimentation experience remotely over the internet.

In many higher institutions of learning like Makerere University, the number of students admitted to Engineering disciplines has greatly increased in the recent past years but the resources (equipments and laboratory technicians, financial resources and space) to adequately train them using the conventional workshop/Laboratory based approaches have not increased proportionately. However technological advancements in education have opened doors to Remote Engineering in Education [2].

Sophisticated technologies such as the iLabs Shared Architecture (ISA), National Instruments Laboratory Virtual Engineering Workbench (NI LabVIEW) Software Package, and National Instruments Engineering Laboratory Virtual Instrument Suite (NI ELVIS II) Prototyping Board enable remote access to laboratory equipment. This allows institutions to gain leverage on the few very expensive equipment available so as to reinforce theoretical concepts delivered in lectures.

1.1.1 Digital Signal Processing

It is difficult to connect Mathematical concepts in Digital Signal Processing (DSP) and Network theory with their practical engineering applications. However many “recipes” suggest “visualization” of DSP theory [3]. LabVIEW software package provides a standardized simpler way of visualizing DSP and Network theory concepts.

LabVIEW provides a graphical development environment with built-in functionality for simulation, data acquisition, instrumentation, measurement analysis, and data presentation. The User Interface (UI) is created by “drag-and-drop” of pre-defined objects [4]. LabVIEW Graphical applications which are known as Virtual Instruments (VIs), “mimic” real measurement and control instruments such as oscilloscopes, voltmeters, ammeters, functional generators, Bode analyser, DMM (Digital Multi-meter) etc. [5]. These VIs are used to exploit the potentials of hardware platforms to the full extent.

LabVIEW standard filter palettes possess a range of tools for synthesis and analysis of filters. Instead of the expensive and bulky lab equipments in DSP Labs, it is more appropriate to use NI LabVIEW software package in combination with NI-ELVIS II+ hardware developing platform and a personal computer.

1.1.2 Designing of Digital and Analog Filters

Two types of digital filters were considered, namely IIR and FIR. The design of IIR filters is closely related to the design of analog filters. An analog filter is normally designed and a transformation carried in the digital domain using either impulse invariant transformation or bilinear transformation. In this research, the focus was placed on designing minimum order IIR filters to meet a set of specifications using LabVIEW function with each design accompanied by a plot of its frequency response, impulse response and pole-zero diagrams [8].

The design procedure of analog filters has two distinct stages. In the first stage, a frequency response function H (jw) was derived to meet a set of specifications. In the second stage, an electronic circuit was designed to generate the frequency response function. Filter circuits can be constructed entirely from passive components or can contain active components such as operational amplifiers [7]. The transmission of data from the NI-ELVIS 11 board platform to the computer and vice versa was carried out over the USB media.

1.2 Problem

With the rapid advancement in software and hardware developments in DSP especially in the areas of audio, image and video processing, it is vital for students to complement their theoretical learning with practical applications. At Makerere University, School of Engineering, the BSc. Electrical, BSc. Telecommunications, and BSc. Computer Engineering curricula contain courses in analog signal processing and digital signal processing.

However, these courses are taught theoretically during lectures. The DSP course is taught in the fourth year of study to all programs in the Department of Electrical and Computer Engineering. There are no practical sessions held to supplement the theory learnt during normal lecture time. Therefore, students do not get ample time to explore and understand DSP concepts practically and to understand the trade-offs between analog and digital filters. Moreover, the laboratory resources available do not provide a comprehensive experience to explore the practical study of DSP.

Also, in the Electronics laboratory, there are only four pieces of CK342K boards which, when compared to the increasing numbers of students, cannot be enough for individual practical exploration of the study.

Although the iLabs platform has been modified to expand its functionality to include experiments in DSP to supplement the conventional laboratories, these experiments do not provide practical hands-on experience.

1.3 Objectives

The main objective of this project was to design and implement an interactive analog and digital filters laboratory for deployment on the ISA to supplement the existing conventional laboratories. The specific objectives were;

1. To design analog and digital filters (high-pass, low-pass, band-pass and band-stop) operation and the trade-offs between them.
2. To explore the use of LabVIEW virtual interactive DSP experiments and hardware DSP laboratory tools on the NI-ELVIS II + development platform to design digital signal processing experiments.
3. To demonstrate concepts of sampling, under sampling, aliasing, anti-aliasing filter, and windowing as applied to DSP.
4. To determine the stability, zeros and poles for different digital filter topologies.

2.0 METHODOLOGY

2.1 Design tools and Requirements Specification.

The methods, tools and processes employed in the design and development of this project included; designing of analog filters circuits, designing of digital filters (IIR and FIR) using DSP LabVIEW toolkits, designing of express VIs to illustrate DSP concepts of sampling using DSP LabVIEW toolkits, aliasing, Digital to Analog Converter (DAC) and Analog to Digital Converter (ADC), designing of a LabVIEW search engine connected to Google, and designing of a remote panel connection to the lab. Using passive and active components to design Analog circuits, relay switches to toggle between different filters together with the NI-ELVIS 11 prototyping board. The design process involved requirements specification as shown in Table 1 below.

Table 1: Requirement Specification for Analog and Digital Filters

No 1	Hardware for Analog Filters	Component specification
1	OPAMP (6)	LM741
2	Resistors (watt)	1.2kΩ (4), 10kΩ (4), 1kΩ (2)
3	Electrolytic Capacitors	1μf (4), 10nf(4)
4	Jumper wires	4 packs each consisting 50 jumper wires

5	NI ELVIS 11 Board (2)	Consists of a function generator, Oscilloscope, digital multi-meter, DC power supply(±15V, 5V, GND), Bode analyzer, Digital I/O
6	Contact Relay (4 of them)	SRD-05VDC-SL-C
7	Transistor (4 of them)	TIP122
No 2	**Software**	**Purpose**
1	Multisim 13.0	Simulation
2	LabVIEW 2013 with DSP toolkit (For digital filters)	Signal acquisition and representation

2.2 Technology Description

2.2.1 Analog Filters

The design of analog involves signal acquisition, signal filtering, signal representation and analysis. With LabVIEW 2013 launched, the NI bode analyser express VI is accessed to be used to acquire signals from the NI ELVIS 11 BOARD.

2.2.2 Signal Acquisition

On the LabVIEW 2103 Block diagram, NI ELVIS Bode analyser is used to measure the gain and phase shift versus frequency for passive and active linear circuits of the acquired signal from the NI ELVIS board.

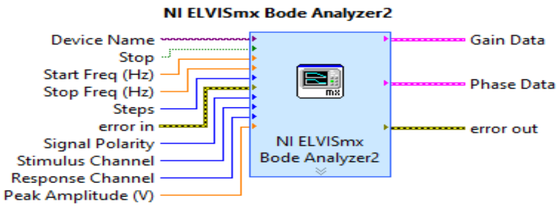

Figure 4: NI ELVISmx Bode Analyser

2.2.3 Digital Filters

The main digital filters, FIR and IIR were designed. The design of digital filters involves signal acquisition, representation and analysis. Using the LabVIEW DSP MODULE the following express VIs were used for filtering and signal representation: Function Generator, NI AAI Base.lvlib: Equi-Ripple LowPass.vi, NI_AAI Base.lvlib: Equi-Ripple HighPass.vi, Data Acquisition Unit (DAQ) Assistant.

2.3 Designing of Analog filters

2.3.1 Analog Filter circuit design

Using Multisim 13.0 software, simulations of analog (Low-pass, High-pass and Band-pass) filters were of performed using the ideal LM741 Op-Amps, Capacitors, Resistors and power supplies. The aims of these simulations were;

1. To obtain the theoretical gain and phase graphs of the filters
2. To obtain the cut off frequency
3. To build confidence in constructing analogue circuits.

2.3.2 High-pass filter design

It was implemented using the LM741 Op-Amp, two 1μF capacitors and two 1.2kΩ resistors. Excitation of the filter was provided by the LabVIEW function generator. *Figure 2* shows a simulated circuit diagram of the HP filter with a cut-off frequency of about 132.6 Hz, and the gain and phase bode plots obtained from the physical circuit using the NI ELVISmx Instrument Launcher Bode Analyzer.

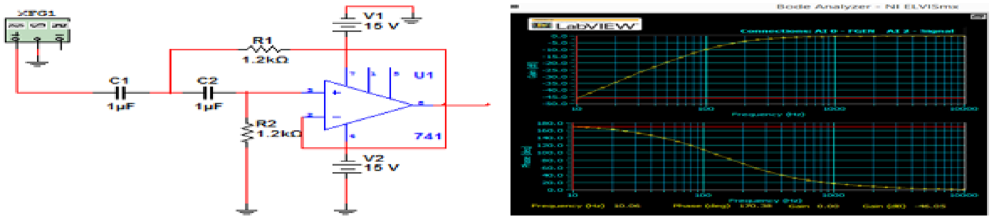

Figure 2: HP Multisim circuit, Gain and phase bode plots

2.3.3 Low-pass Filter Design

It was implemented using the LM741 operational amplifier, two 1kΩ resistors and two 10nF capacitors. Excitation of the filter is provided by the LabVIEW function generator. The low pass filter has a cut off frequency is Hz $F_c = 1591.5$ Hz

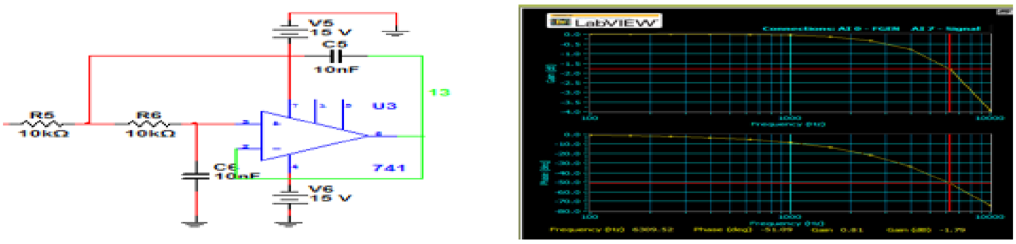

Figure 3: LP Multisim circuit. Gain and bode plots

2.3.4 Band-pass Filter Design

It was designed as a cascade connection of a HP and LP filters. It consists of three levels; HP filter, amplifier of gain A = 11, and LP filter. Each level contains an LM741 Op-Amp resistors and capacitors.

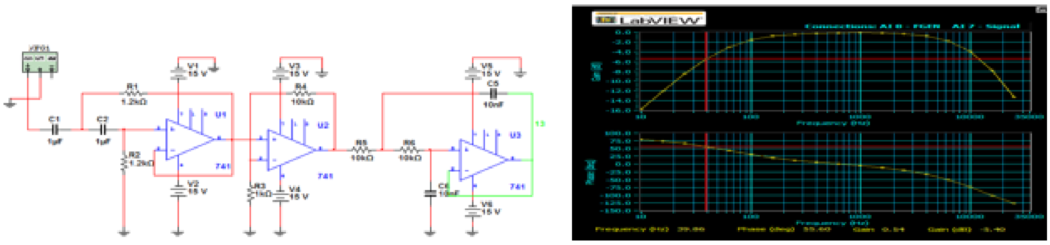

Figure 4: BP circuit, Gain and Phase bode plots

2.3.5 Low-pass, High-pass and Band-pass Filters inter-connected with relay circuit

A relay circuit was built to enable a remote user who is interfacing with the lab to be able to switch between different filters types. *Figure 5* below shows the combined circuit. The circuit board is then connected to a computer through USB type B. With LabVIEW 2013 launched, the NI bode analyser express VI is used to acquire signals from the NI ELVIS 11 board.

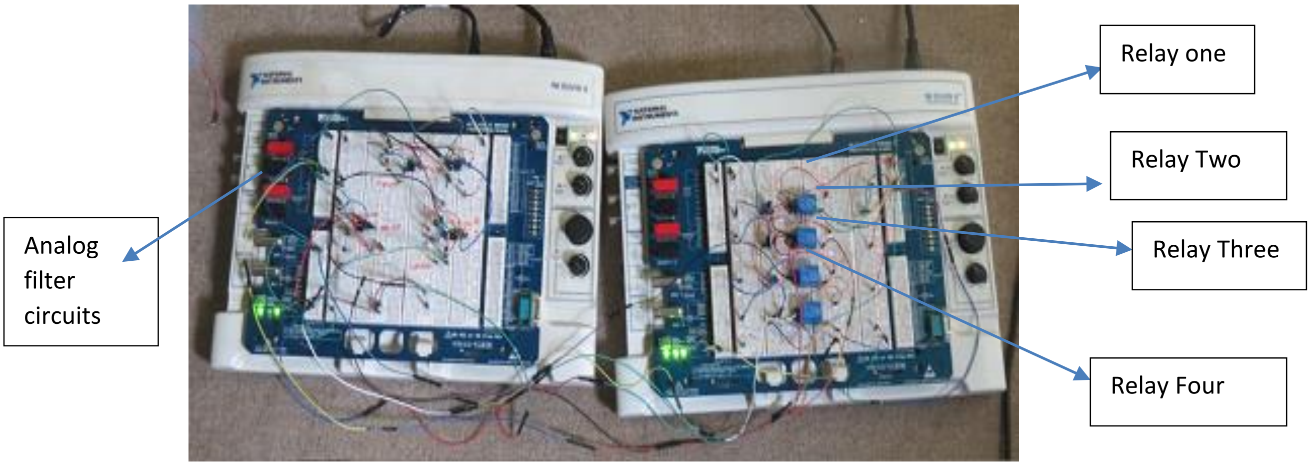

Figure 5: Low pass, High Pass and Cascaded Band Pass Filter

3.0 DISCUSSION OF RESULTS

3.1 Results of Analog Filters

3.1.1 Low-pass Analog Filter GUI

When RELAY ONE is closed, keeping the other relays open, a LED lights green showing that relay one has been activated to in order to bias the Low-pass filter. For an input sinusoid waveform of amplitude 2V, the output waveform picked from Pin 6 of the LM741 Op -Amp has an amplitude of 0.1 as shown in *Figure 6*. The Low-pass filter passes signals whose frequency is lower than its cut-off frequency $f_c = 1591.5\ Hz$ without significant attenuation while signals with frequencies higher than the cut-off one are attenuated.

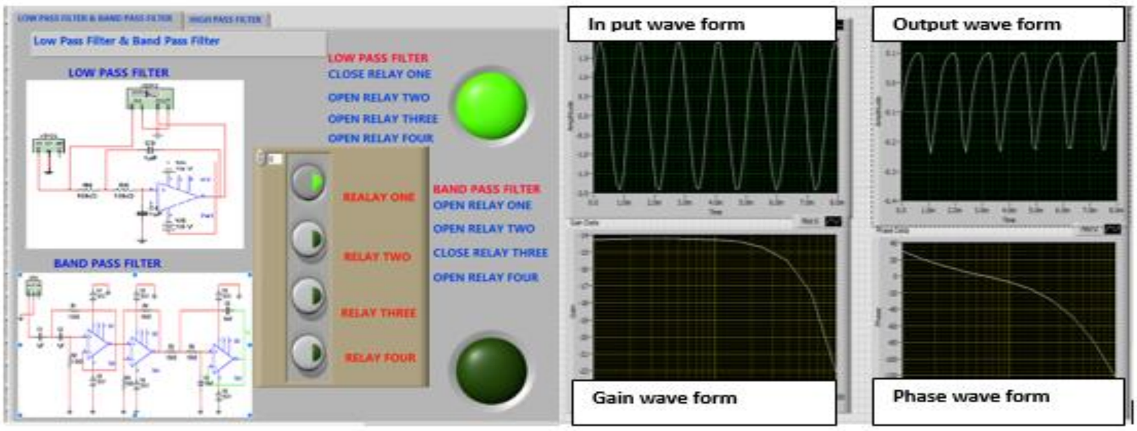

Figure 6: Wave form graphs for LP filter

3.1.2 High pass filter GUI

When RELAY FOUR is closed keeping RELAY ONE, RELAY TWO AND RELAY THREE open, a LED lights green showing that RELAY FOUR has been activated in order to bias the High-pass filter. As shown in *Figure 7*, the High-pass filter passes signals whose frequency is lower than its cut off frequency 136.2Hz with insignificant attenuation while signals with frequencies higher than the cut-off are passed without attenuation.

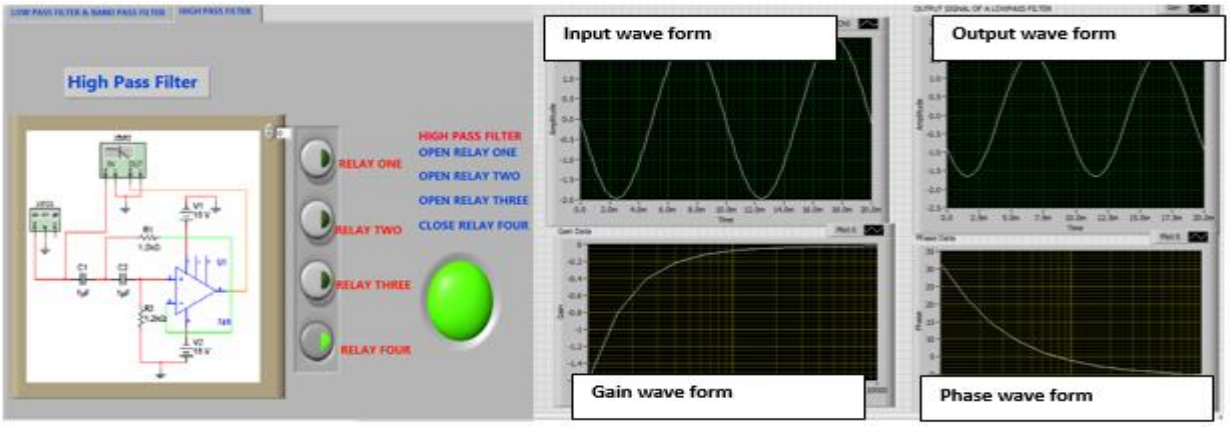

Figure 7: GUI for the High pass filter with relay circuit configurations

3.2 Bandpass analog filter GUI

Closing RELAY THREE and keeping the rest of the relays open, a LED lights green showing that RELAY THREE has been activated in order to bias the High-pass filter. Using the Bode analyser as shown in the gain and phase waveform from Ni ELVISmx palette of virtual instruments, for a band-pass filter with a lower and upper cut off frequencies at 70Hz and 1000Hz, only frequencies in this range are passed. All frequencies outside this range are attenuated as shown in gain and phase waveforms in *Figure 8.*

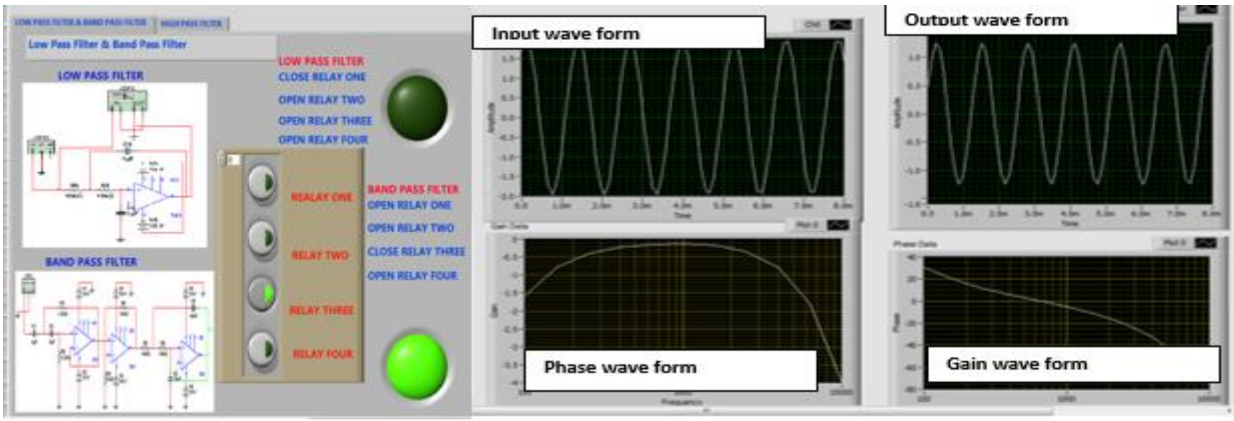

Figure 8: GUI for Band pass filter with wave forms

3.3 Design process and results of Digital Filters

LabVIEW DSP Module and LabVIEW 2013 software were used to design and display results of digital filters. The main digital filters of FIR (High-pass, Low-pass, Band-pass and Band-stop filters), IIR (Butterworth, Chebyshev, Inverse Chebyshev, Elliptic, Bessel) were designed.

3.3.1 FIR filters, a Low-pass filter and band-pass filter

The acquired signal or simulated Gaussian white noise from the computer sound card is filtered with either low pass or band pass filter and results displayed and analysed the LabVIEW user interface as shown in *Figure 9. For example, for the FIR* windowed topology having 50 taps, Lower pass band = 1200Hz, Upper pass band = 3000Hz, Lower stop band = 500Hz, Upper stop band = 3500Hz, Scale = 12.85 and 100 samples, the Gaussian white noise wave form obtained from the computer sound card and the output filtered wave form for a Low-pass and Band-pass FIR filters were displayed as in *Figure 9.*

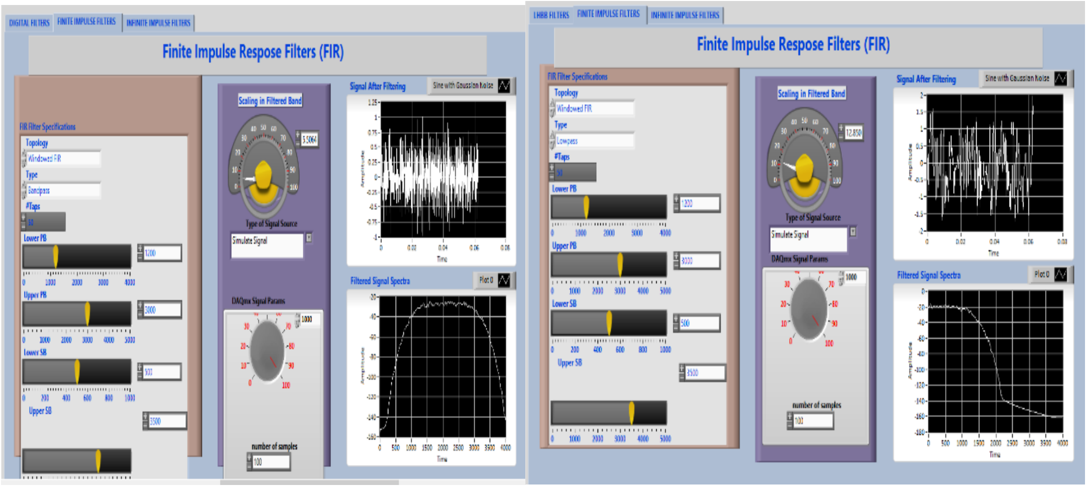

Figure 9: Low pass and Band-pass FIR filter

3.3.2 IIR filters Digital Filter Topologies.

Figure 10 shows the magnitude response and the pole-zero plot of an inverse Chebyshev lowpass filter with the filter parameters set as follows: Cutoff frequency = 500 Hz, Stop frequency = 1000 Hz, Passband attenuation = 15 dB, Stopband attenuation=100dB, Sampling rate = 10951 Hz, Order = 10. If the order of the filter is increased while keeping the other specifications constant, the magnitude response plot slope becomes steeper.

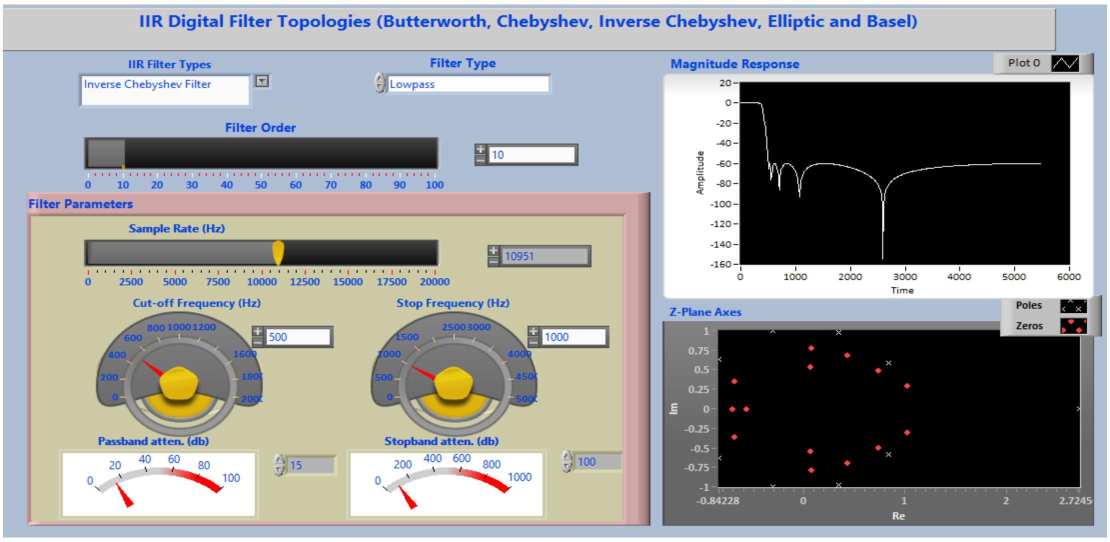

Figure 10: UI showing Magnitude response and Pole-Zero Plot of a 10th Order Inverse Chebyshev Filter

Results for Butterworth, Chebyshev, Elliptic and Basel filters are obtained in a similar way by selecting the filter of interest from the user interface shown in Figure 10.

3.3.3 Aliasing, Sampling, Quantization, and Signal Reconstruction

The original signal and the reconstructed were displayed on the same graph as shown in *Figure 11* below. The Discrete waveform, Digital waveform, Analog frequency, Digital frequency and the Number of samples skipped are also displayed on the user interface enabling the experimenter to examine proper signal sampling and reconstruction.

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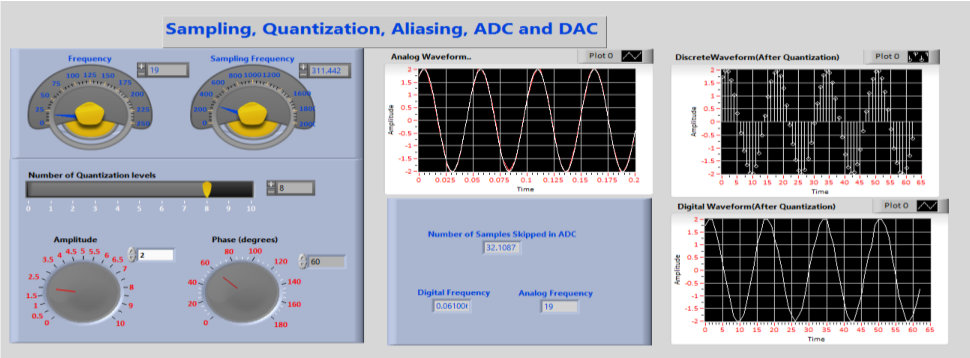

Figure 11: User Interface for Aliasing, Sampling, Quantization, or Signal Reconstruction

From digital and analog filters explored above, the frequency response of digital filters indicated better roll-off and stopband attenuation than for analog filters. Analog filters have ripples in the passband. Any amount of flatness achievable with analog filters is limited by the accuracy of their resistors and capacitors. On the other hand, digital filters are nearly perfectly flat. For Analog filters, a theoretical result has it that Chebyshev Type I have a response lower than that of Butterworth filters. Practical results however indicated that the shaping factor of a Chebyshev type I is less than that of a Butterworth.

4.0 LIMITATIONS AND POLICY IMPLICATIONS

4.1 Limitations of the study

During designing of analog filters, it was difficult to identify proper criterion for selecting ICs, resistors and capacitors with low noise, response time and harmonic distortion. This is because analog electronics are generally nonlinear. The distortion and electronic noise due to the passive components especially resistors and the input filtering capacitors, proved difficult to greatly minimize. On the other hand, digital filters took a tremendous amount of time to design and develop.

4.2 Policy implications

A recent survey of engineering training institutions in Uganda by the Engineers Registration Board (ERB) in 2018 revealed that, many universities and technical institutions offering engineering programmes especially in electrical, computer and telecom engineering are understaffed and inadequately equipped due to limited financial resources. This online laboratory and many others developed under iLabs@MAK would provide opportunity to financially constrained institutions to share very expensive laboratory equipments cheaply.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Analog and digital filters are very important in signal processing. Whereas analog filters are implemented using hardware, digital filters are implemented using software. For analog filters, the use of an LM741 operational amplifier greatly simplified their implementations as low-pass, high-pass, band-pass and band-stop.

The windowing method was used to design digital FIR filters because of its simplicity. Moreover, LabVIEW provides in-built FIR functions such as the Hamming window, Gaussian window and Kaiser Window which further simplified the design process. A combination of the NI ELVISmx virtual instrument and LabVIEW user interface made it possible to remotely control and monitor the behaviour and nature of waveforms for different configurations of both the analog and digital filters. The laboratory also enables exploration of the DSP concepts of sampling, under sampling, aliasing, anti-aliasing filter, and windowing.

5.2 Recommendations

The input filtering capacitors can be precisely specified so as to minimize nonlinearity in analog filters. For digital filters, oversampling a signal at twice Nyquist rate can be used to relax the filter roll-off. For practical applications however, the selection of which filters to use requires identification of whether the application requires a Linear phase response or not, ripples and narrow transition band. Further research should be carried out on how to make the students' experience as close as possible to a physical laboratory experience.

5.3 Acknowledgement for funders

This work was supported by the iLabs@MAK Project and the Department of Electrical and Computer Engineering, Makerere University.

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Vol 4, 2019 Issue, ISSN 2001-2837, Pages 1-89

A Fit-For-Purpose Approach to Land Administration in Africa - supporting the 2030 Global Agenda

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ABSTRACT

Land is the most important resource for many developing countries in Africa to achieve the sustainable development goals. Yet many African countries are faced with various problems often causing land conflicts, reducing investments and economic development, and preventing countries reaching their true potential. Africa and other developing countries will not efficiently utilize their land resources as a means to overcome these challenges, unless they drop the approaches to security of tenure, many of which, were introduced during colonial times, but have not helped in securing land tenure rights for a significant proportion of their populations, in a non-discriminatory manner, that leaves no body behind.

In this paper, we describe the key principles for building flexible, universal and sustainable Fit for Purpose (FFP) land administration (LA) systems in African countries, as a better alternative to conventional approaches that focus on unrealistic accuracy standards and complex legal procedures. The discussion informed by a review of literature on Fit for Purpose Land Administration, the sustainable development goals, and the authors experience on land administration systems in Africa and globally. Furthermore, two experiences from Rwanda and Uganda are introduced to demonstrate that building FFP land administration systems is a viable solution to solving the global security of tenure divide.

We conclude that implementation of Fit for Purpose Land Administration approach requires political support at national and local level, to facilitate the change process, and in embedding FFP LA provisions into national and local laws. Likewise, effective capacity building is fundamental to the success of such programs. Professionals and the general society must understand that these simpler, less expensive and participatory methods are just as effective and secure as conventional land surveying methodologies and judicial recordation procedures. Finally, involvement of development partners such as Global Land Tool Network (GLTN), The World Bank, United Nations Global Geospatial Information Management (UN-GGIM), The United Nations Human Settlements Programme (UN- HABITAT) and Food and Agriculture Organization of the United Nations (UN FAO) is key in ensuring that the land administration projects technically and financially supported are designed around FFP concepts.

Keywords: Fit for Purpose, Land Administration, Africa, SDGs,

1.0 INTRODUCTION

Most less developed countries are struggling to find remedies for their many land problems that are often causing land conflicts, reducing investments and economic development, and preventing countries reaching their true potential. Existing investments in land administration have been built on legacy approaches, have been fragmented and have not delivered the required pervasive changes and improvements at scale.

The solutions have not helped the most needy - the poor and disadvantaged that have no security of tenure. Infact the beneficiaries have often been the elite and organizations involved in land grabbing. It has therefore become necessary to rethink the approaches to devise new solutions that can deliver security of tenure for all, are affordable and can be quickly developed and incrementally improved over time. The Fit-For-Purpose (FFP) approach to land administration has emerged to meet these simple, but challenging requirements.

This paper describes the key principles for building sustainable and FFP land administration systems in African countries where often less the 10 per cent of the land and population is included in the formal systems. The paper argues that building such FFP land administration systems is the only viable solution to solving the global security of tenure divide. The FFP approach is flexible and includes the adaptability to meet the actual and basic needs of society today and having the capability to be incrementally improved over time. This will be triggered in response to social and legal needs of economic development, investments and financial opportunities that may emerge over the longer term. In this FFP approach, land rights can be secured for all in a timely and affordable way.

2.0 LAND ADMNISTRATION AND THE 2030 GLOBAL AGENDA

There is a broad agreement that, while the MDGs provided a focal point for governments, they were too narrow. The MDGs are now replaced by the Sustainable Development Goals (SDGs) with a new universal set of 17 Goals and 169 target that UN member states are committed to use to frame their agenda and policies over the next 15 years (see Figure 1). The goals are action oriented, global in nature and universally applicable. Targets are defined as aspirational global targets, with each government setting its own national targets guided by the global level of ambition, but taking into account national circumstances. The goals and targets integrate economic, social and environmental aspects and recognise their interlinkages in achieving sustainable development in all its dimensions. While the MDGs did not mention land directly, the new SDGs include several goals with a significant land component mentioned in the targets (see Table 1). For example, Goal 1 calls for ending poverty in all its forms everywhere, and target 1.4 states that by 2030 all men and women will have equal rights to ownership and control over land and other forms of property.

Figure 1: The Sustainable Development Goals (Adopted from UN, 2015).

Similarly, the land component is referred to in target 3 of Goal 2 on ending hunger, and, more generally in Goal 5 on gender equity, Goal 11 on sustainable cities, Goal 15 on life on land, and Goal 16 on peace, justice and strong institutions. These goals and targets will never be achieved without having good land governance and well-functioning country-wide land administration systems in place.

Table 1: Link between Land Administration and SDGs

Goal No.	Focus	Relevant to Land Administration
1	End poverty in all its forms everywhere	Poverty eradication programs, more especially in Africa and other developing countries are largely based on efficient utilization of land and natural resources.
2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture	Food security and sustainable agriculture are dependent on land efficient utilisation of land
3	Ensure healthy lives and promote well-being for all at all ages	Ensuring healthy lives is partly related to land administration given that good landuse planning approaches can create healthy living conditions, for example by improving sanitation.
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	This goal in indirectly related to land administration. Education facilities require planning and allocation of land.
5	Achieve gender equality and empower all women and girls	Land administration resents a unique opportunity for promoting gender equality and empowerment given that many African communities are dependent on land for livelihoods.

Goal No.	Focus	Relevant to Land Administration
6	Ensure availability and sustainable management of water and sanitation for all	Sustainable management of water resources and sanitation are dependent on proper landuse planning and sustainable utilisation of land resources.
7	Ensure access to affordable, reliable, sustainable and modern energy for all	Provision of sustainable energy such as hydro, biogas have a direct bearing on land administration given that most of the resources require land allocation, planning and investment.
8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Effective management of land and natural resources contribute to economic growth and are sources of employment
9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Infrastructure and industrialisation require access to land
10	Reduce inequality within and among countries	Indirectly related to land administration given that developing countries' main option is to utilise land and natural resources so as to bridge the gap between the first and third world countries.
11	Make cities and human settlements inclusive, safe, resilient and sustainable	Resilient and sustainable cities require urban planning, which require good land administration practices.
12	Ensure sustainable consumption and production patterns	Indirectly linked to land where consumption and production are related to use of land and natural resources
13	Take urgent action to combat climate change and its impacts	Climate change adaptation and mitigation measures require responsible use of land and natural resources.
14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	The definition of land extends to oceans and seas implying a directly relationship between land administration and this goal.
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Sustainable use of natural ecosystems requires sound land management practices.
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	Indirectly linked to land administration more especially on access to land.

Goal No.	Focus	Relevant to Land Administration
17	Strengthen the means of implementation and revitalize the global partnership for sustainable development	Sustainable development links with land administration especially where development is based on investment in land or use of land as capital.

The SDGs, thereby, provide a framework around which governments, especially in developing countries, can develop policies and overseas aid programmes designed to alleviate poverty and improve the lives of the poor, as well as a rallying point for NGOs to hold them to account. In other words, the SDGs is a key driver for countries throughout the world – and especially developing countries – to develop adequate and accountable land policies and regulatory frameworks for meeting the goals.

There is strong request for effective monitoring and assessment of progress in achieving the SDGs. There is a need for reliable and robust data for devising appropriate policies and interventions for the achievement of the SDGs and for holding governments and the international community accountable. Such a monitoring framework is crucial for encouraging progress and enabling achievements at national, regional and global level. This calls for a "data revolution" for sustainable development to empower people with information on the progress towards meeting the SDG targets (UN, 2014, p.7). For example, the 2014 progress report showed that the extreme poverty rate had been halved and MDGs Goal 1 was thereby met at a global scale - but with huge regional deviations. This was achieved mainly due to the contribution from China where, in 1978, the collective farms were dismantled and replaced by long-term leases to allocate land rights to farming households. This policy enforced an era of agricultural growth that transformed rural China and led to the largest reduction of poverty in history. The percentage of people living in extreme poverty declined from about 80% of the population in 1981 (the highest in the world at that time) to only 13% in 2008. In the same way, in Vietnam, the extreme poverty was reduced from 58% in early 1990s to 15% in 2008.

On the other hand, even if the Sub-Saharan Africa has seen a considerable growth rate of above 5% per year for more than a decade, this region remains poor for the most part and has been unable to translate its recent robust growth into rapid poverty reduction (Byamugisha, 2013). This underpins the necessity of detailed monitoring at regional and local / country level.

It should be recognised, that, next to the SDGs, the wider global agenda includes a range of global issues such as responsible governance of tenure, human rights and equity, climate change and natural disasters, rapid urbanisation, and land conflict situations, see Figure 2 (Enemark, 2014).

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Figure 2: The Wider Global Agenda

3.0 FOCUS ON AFRICA

Sub-Sahara Africa is often referred to as an underdeveloped region with a great potential, but Africa is now on the move. Economic growth in Sub-Sahara Africa is considerable having a rate of above 5 per cent per year for more than a decade. Projections by the World bank indicate that this will continue for the years ahead while the global economy will grow at only 2.5 per cent (and only about 1 per cent in Western economies). So Africa is expected to grow twice as fast as the global economy.

However, Sub-Sahara Africa is still mostly poor and has been unable to translate its recent robust growth into rapid poverty reduction. Compared to other developing regions, Sub-Sahara Africa has generally been left behind and is struggling with issues such as insecurity of tenure, informal settlements and urban slums, landownership inequalities and landlessness, and degradation of the environment and natural resources (see Figure 5). These facts indicate that poor land governance, including the manner in which land rights are defined and administered, may be the root of the problem.

The global agenda is very much about bringing this map back to scale through poverty eradication, improving education and health, facilitating economic development, encouraging good governance and ensuring sustainability.

In recent years, significant progress has been achieved in countries such as Rwanda and Ethiopia through comprehensive land reform projects and other countries are following in the footsteps. At the regional scale the challenges are addressed by setting a promising agenda for Africa and by focusing on sustainable land governance as the core means to achieve the goals. The overarching agenda is set by the African Union, the African Development Bank, and the UN Economic Commission for Africa. It is adopted by the African leaders through two seminal documents “Declaration on land Issues and Challenges in Africa” and the “Framework and Guidelines on Land Policy in Africa” (AUC/UNECA/ADB, 2009).

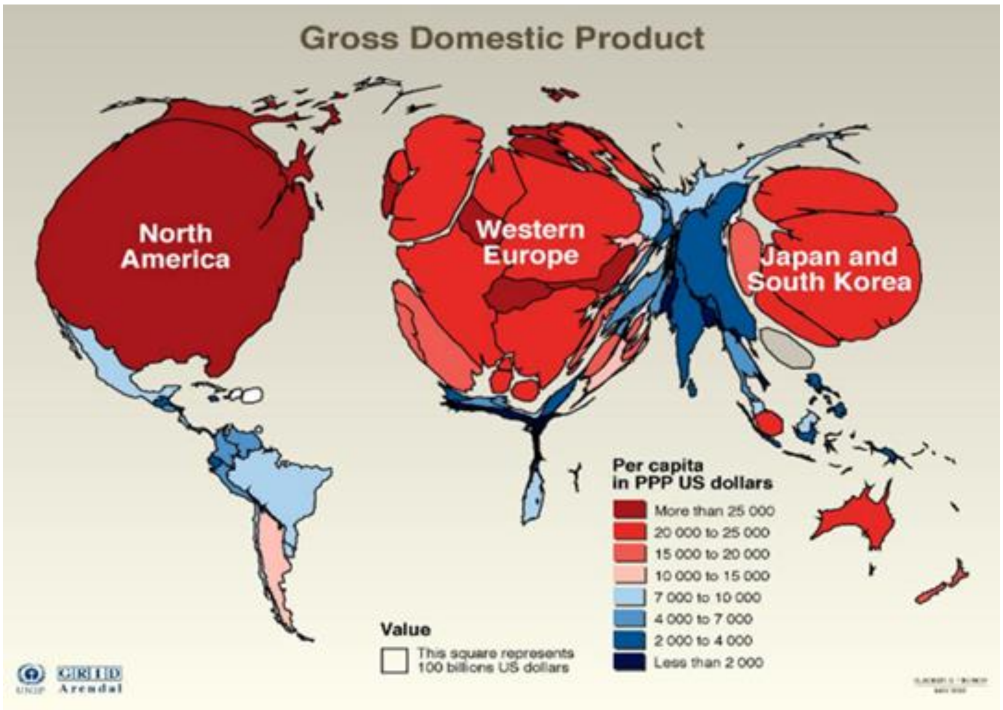

Figure 5: A hypothetical map of the world generated by using the GPD as the scale for territorial size. The so-called western regions – North America, Western Europe, South Korea and Japan ‘balloon’, while other regions such as Africa almost disappear (Adopted from UNEP, 2007)

But developing land policies is not an end in itself – they need to be effectively implemented. This relates to land reform programmes, land administration infrastructures and building of transparent and sustainable institutions.

4.0 LAND GOVERNANCE

The organizational structures for land governance and administration differ widely between countries and regions throughout the world and reflect the cultural and judicial setting of the country and jurisdiction. Sound land governance requires a legal and regulatory framework, operational processes and capacity to implement policies consistently within a jurisdiction or country in sustainable ways. In this regard, land administration systems provide a country with an infrastructure for implementing land policies and land management strategies in support of sustainable development (see Figure 4)

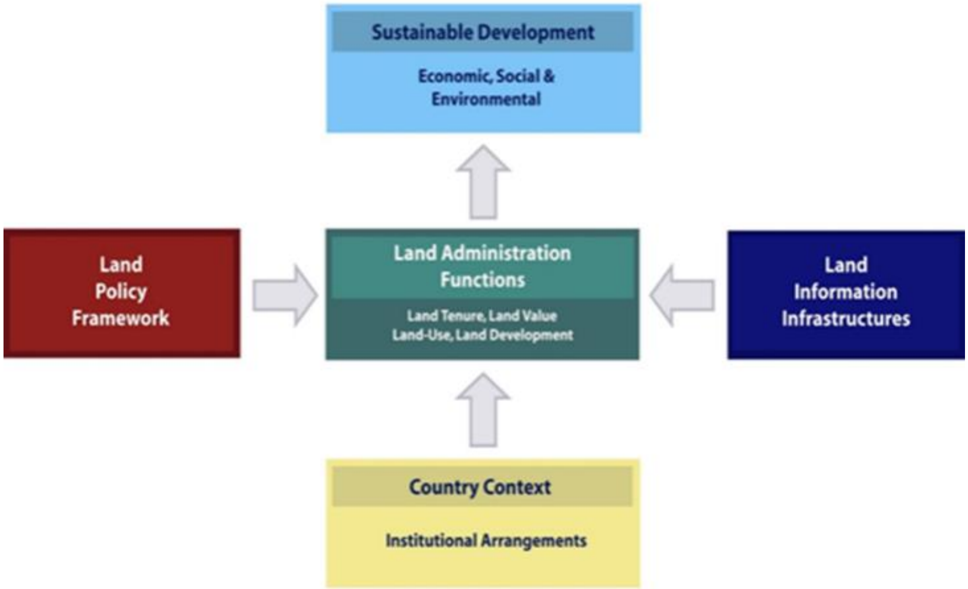

Figure 4: The Land Management Paradigm (Enemark, 2004, Williamson et.al. 2010)

Sound land governance requires a legal and regulatory framework, operational processes and capacity to implement policies consistently within a jurisdiction or country in sustainable ways. In this regard, land administration systems provide a country with an infrastructure for implementing land policies and land management strategies in support of sustainable development. The operational component of the land governance concept is the range of land administration functions including:

- land tenure (securing and transferring rights in land and natural resources);
- land value (valuation and taxation of land and properties);
- land use (planning and control of the use of land and natural resources); and
- land development (implementing utilities, infrastructure, construction works, and urban and rural developments).

These functions interact to deliver overall policy objectives, and they are facilitated by appropriate land information infrastructures that include cadastral and topographic datasets linking the built and natural environment.

A land administration system provides governments with an infrastructure for securing land tenure rights, determining valuation and taxation of land and managing its use and development. It sits within the principles of responsible land governance in the framework of national land policies (Enemark, et.al., 2016) .

5.0 CONTEXTUALISING THE FIT-FOR-PURPOSE APROACH

In the context of building sustainable land administration systems in developing countries, the term “Fit-For-Purpose” means applying the spatial, legal, and institutional methodologies that are most fit for the purpose of providing secure tenure for all. This approach will enable the building of national land administration systems within a reasonable timeframe and at affordable costs. The systems can then be incrementally improved over time.

The FFP approach starts by identifying and analysing the purpose(s) that the systems are intended to serve and then deciding on the adequate means to be applied for meeting the purpose(s). This means that systems should be designed to meet / fit the purpose(s) rather than just following some rigid set of regulations and demands for accuracy. These unnecessary constraints, often imposed during colonial times, result in systems that are unsustainable and frankly unattainable at a national wide scale for developing countries. In this regard, of course, political commitment, corruption, largesse and a range of other factors play in as well.

The FFP approach focuses firstly on defining the “what” in terms of the end outcome for society and communities and then, secondly, it looks at the implementation design of “how” this could be achieved. Or to put it another way, the means (the “how”) should be designed to be the most “fit” for achieving the purpose (“what”). A catch phrase for this approach used in New Zealand is “As little as possible – as much as necessary” (Grant and Haanen, 2007). This is just another way of saying “Fit-For-Purpose”.

It is clear that the implementation proposed here is significantly different from the more advanced systems embedded in many western economies. This could lead to concerns that, by not following modern best practice for land administration as implemented predominantly in the Western world, then developing countries might be wasting precious resources on building systems that will prove to be outdated and ineffective.

What is usually forgotten in this discussion is that the advanced land administration systems of developed economies did not suddenly appear fully formed in those countries. In most developed countries, the initial cadastral and registration systems were implemented very roughly and quickly – rough even by the standards of the day. These rough methods were fit for the purpose for the society at that time – and the result was a quickly developing and vibrant society and economy. As those societies and economies developed, the methods that had once been fit for the purpose were, several decades later, seen to be no longer fit. Governments undertook formal reviews, reports were written, the old ways were condemned as inadequate and new FFP system upgrades were designed. What was easily forgotten was how well those rough and ready methods had served to quickly build and advance the societies that outgrew them. Developing countries have better opportunities to develop even more improved systems given that advances in technology have reduced the cost but also increased the accuracy of capturing land administration data.

Three key characteristics of FFP Land Administration Approach

The FFP approach, as illustrated in **Error! Reference source not found.** below, has three fundamental characteristics:

- Focus on the purpose. This new approach is focused mainly on the purpose of providing secure tenure for all. The means to achieve this should then be designed to be the most “fit” for achieving this purpose rather than blindly being guided by rigid standards for accuracy and top-end technological solutions
- Flexibility. The FFP approach is about flexibility in terms of demands for accuracy, and for shaping the legal and institutional frameworks to best accommodate societal needs. The FFP approach also includes the flexibility to meet the need for securing different kinds of tenure types, ranging from more social or customary tenure types to formal types such as private ownership and leasehold.
- Incremental improvement. The systems should be designed for initially meeting the basic needs of society today. This will identify the optimal way of achieving this by balancing the costs, accuracy and time involved. This creates what is termed a “Minimum Viable Product”. Incremental upgrading and improvement can then be undertaken over time in response to emerging needs and opportunities.

These three characteristics underpin the FFP concept, consisting of three core components: the spatial, legal & regulatory and institutional frameworks (see Figure 5 below). Each of the three frameworks has four corresponding key principles as presented in Table 2 below.

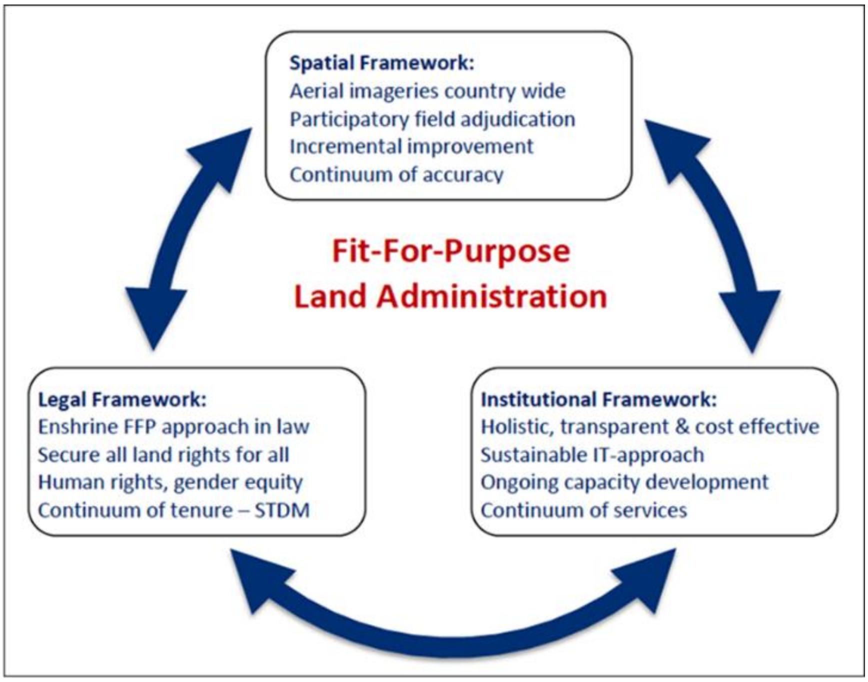

Figure 5: The Fit-For-Purpose Concept (Enemark, et al., 2016)

5.1 The FFP Concept.

The FFP concept includes three core components: the spatial, the legal, and the institutional frameworks. Each of these components includes the relevant flexibility to meet the actual needs of today and can be incrementally improved over time in response to societal needs and available financial resources. This means that the concept – in itself – represents a continuum. The three framework components are interrelated and form a conceptual nexus underpinned by the necessary means of capacity development.

The spatial framework aims to represent the way land is occupied and used. The scale and accuracy of this representation should be sufficient for supporting security of the various kinds of legal rights and tenure forms through the legal framework as well as for managing these rights and the use of land and natural resources through the institutional framework. The FFP approach therefore needs to be enshrined in the land laws, and for administering this regulatory set-up the institutional framework must be designed in an integrated, transparent and user-friendly way. This administration again requires reliable and up to date land information that is provided through the spatial framework.

The FFP concept, this way, encompasses a dynamic interaction of the spatial, legal, and institutional framework for achieving the overall land policy objectives and outcomes for society and communities – and each of the frameworks can be incrementally improved over time. These dependencies need to be carefully coordinated to ensure that the frameworks are mutually reinforcing. For example, if legitimate rights are recognized, then the legal framework will have to be modified to legally enshrine the tenure type, ICT solutions will have to be adapted to support overlapping rights and new relationships prevalent in social tenures, and data recording procedures in the spatial framework modified to capture these relationships.

Key principles. The FFP approach includes four key principles for each of the three frameworks as outlined in Table 2

Table 2: The key principles of the Fit-for-Purpose approach to land administration (Enemark, et al.,2016).

KEY PRINCIPLES		
Spatial framework	**Legal framework**	**Institutional Framework**
▪ Visible (physical) boundaries rather than fixed boundaries; ▪ Aerial / satellite imagery rather than field surveys; ▪ Accuracy relates to the purpose rather than technical standards; ▪ Demands for updating and opportunities for upgrading and ongoing improvement.	▪ A flexible framework designed along administrative rather than judicial lines; ▪ A continuum of tenure rather than just individual ownership; ▪ Flexible recordation rather than only one register; ▪ Ensuring gender equity for land and property rights.	▪ Good land governance rather than bureaucratic barriers; ▪ Integrated institutional framework rather than sectorial silos; ▪ Flexible ICT approach rather than high-end technology solutions; ▪ Transparent land information with easy and affordable access for all.

The key point is that the systems should enable secure land rights for all and cover all land as a basis for land valuation and land use control. At the outset, the systems may vary from being very simplistic in some (rural) areas of the country while other (densely populated) areas are covered by more accurate and legally complete applications, especially where land is of high value and in short supply. Through updating and upgrading procedures, the systems can then, in turn, develop into modern and fully integrated systems for land information and administration, where appropriate. The systems should also allow for recording and securing all types of land rights including informal and social kind of tenures. The legal and institutional frameworks have to be adapted to allow for this kind of flexibility and accessibility for all. This change process necessary for implementing a FFP approach to existing land administration systems can start today. The three framework components are described in detail in (Enemark, et al., 2016). In brief, they include the following:

5.1.1 The spatial framework

The spatial framework should predominantly be developed using aerial / satellite imagery for identifying the way land is occupied and used - rather than using field surveys. The imagery will show the actual physical boundaries and, in most cases, these visible boundaries are sufficient for identifying and securing the land right (see Figure 6). By using geo-referenced imagery the identified boundaries can subsequently be vectorised and used as a cadastral index map

Figure 6: Example from Rwanda showing aerial imagery (left), from which the parcel boundaries are easily identified (right). This is essentially a participatory approach undertaken by locally trained land officers Source: Didier Sagashya, Rwanda

Conventional field surveys, handheld GPS or cell phone recording methods may of course be used where relevant, e.g. to identify non-visible boundaries or to capture the situation in dense high value urban areas. The scale and accuracy of the aerial imagery should relate to purpose and will therefore vary according to topography and density of development. The resulting spatial framework can easily be updated and also upgrading over time or whenever relevant, e.g. in relation to implementation of major infrastructure or land development schemes or when boundary disputes occurs.
The process for providing the spatial framework will include the following steps:

i. Producing the aerial imagery at scales according to topography, land use, and building density;
ii. Using the aerial imagery in the field to identify, delineate and adjudicate parcel boundaries (general boundaries), which can be drawn directly on the imagery and the parcels be numbered for reference to the connected land rights;
iii. The resulting boundary framework can be digitized from the imagery to create a digital cadastral map to be used as a basic layer in the land information system or in combination with the satellite imagery.
iv. Alternatively, boundaries can be digitized directly from tablets or other mobile devices uploaded with ortho-rectified aerial or high resolution satellite images. However, this may still require final printing display of the map and validation by parcel owners.

It is always assumed that existing cadastral boundaries are more accurate than new boundaries created using FFP LA. In practice, this assumption may not hold, more especially in countries where crude methods were used to generate cadastral maps in a sporadic manner. FFP LA techniques may produce cadastral maps of better quality in terms of internal consistency and adjacency. In Uganda for example, it became cumbersome to digitize several cadastral maps which had no georeferenced information, or lacked internal consistency or had not been drawn to scale.

Where it is confirmed that significant quality variations exist between existing cadastral boundaries and FFP LA generated boundaries, some measures should be taken to manage the situation. One option would be to build a single system that incorporates parcel boundaries from FFP LA and the existing cadastral boundaries. In this case, information should be included in the database to indicate the techniques used to generate each boundary, and this may be entered as meta-data. Whenever there is an upgrade in the boundary, for example during subdivision, the metadata record should be edited to reflect the change.

Another approach would be to include FFP LA parcel boundaries in the same system but in an independent thematic layer. This results in two cadastral layers of varying quality but resident in the same database. Such a solution needs to be considered during system design to cater for management of transactions from cadastral information in two separate thematic layers. A quality control mechanism needs to be instituted to migrate data from the less accurate layer to the more accurate layer when need arises. This latter approach is being considered in Uganda to integrate data on cadastral boundaries of differing accuracy, mainly from customary tenure on one hand and freehold, leasehold and mailo, on the other hand. The last option is to run two parallel systems with a future plan of merging them. This option is more expensive and presents technical challenges.

5.1.2 The legal framework

The legal framework should be simple, flexible, and designed for decentralized administration rather than judicial decisions. The legal system must be adapted to accommodate the various kinds of land rights and social tenures that do exist rather than just focusing on land titling, ownership and leasehold. The various tenure systems must be enshrined in the land laws. This should allow for security of tenure within various kinds of communities and thereby enable secure land rights for all. The Continuum of Land Rights (UN-Habitat/GLTN, 2008), see Figure 7, and the Social Tenure Domain Model (FIG/GLTN, 2010) should be applied, which provides a standard for representing the people to land relationships independent of the level of formality, legality and technical accuracy. Such flexibility also relates to the recordation that should be organized at various levels rather than through one central register. In Uganda for example, the Land Act 1998, provides for registration of Freehold, Mailo and Leasehold Titles by Registrars at Ministry Zonal Offices and registration of customary and occupancy rights at the subcounty level by recorders. This scenario creates parallel registers at various levels of government. The Ministry of Lands Housing and Urban Development is exploring the use of technology to build an integrated system that facilitates registration of Titles at the Ministry Zonal Offices while permitting recordation of customary land rights at the sub-country. The resulting information is in one system regardless of where registration takes place.

Finally, the principle of gender equity should apply and should be seen first and foremost as a universal human right, independently of any other argument in favour for it.

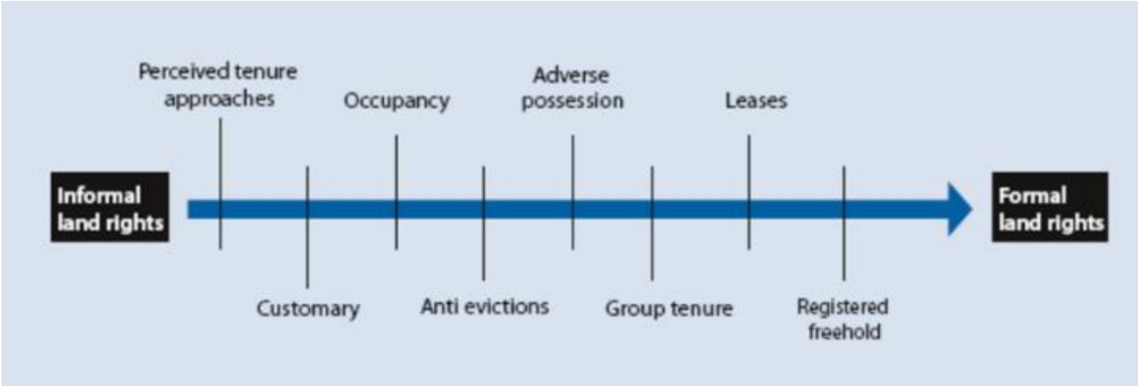

Figure 7: Continuum of land rights (UN-Habitat / GLTN, 2008).

5.1.3 The institutional framework

The institutional framework should be designed for administering the rights in land along with issues related to land valuation and taxation, land use and development. The principles of good land governance should be applied, which prescribes that governments should be legitimate, transparent, accountable, equitable and dedicated to integrity (UN-FAO, 2007).

Furthermore, the Principles of the Voluntary Guidelines for Responsible Governance of Tenure (UN-FAO, 2012) should be applied to ensure efficient, transparent administration of land rights and information with easy access for all. The Guidelines outline principles and practices that governments can refer to when making laws and administering land, fisheries and forests rights. While the Guidelines acknowledge that responsible investments by the public and private sectors are essential for improving food security, they also recommend that safeguards be put in place. These protect tenure rights of local people from risks that could arise from large-scale land acquisitions (land grabbing), and also to protect human rights, livelihoods, food security and the environment. With the help of the Guidelines a variety of actors can determine whether their proposed actions and the actions of others constitute acceptable practices.

Importantly, administration and management of the land administration activities should be organized in a holistic perspective aiming to treat land and natural resources as a coherent whole rather than in isolated sectorial silos. Fundamental to this is the early formulation of a national land policy that provides guidance for a coherent administration of land issues across sectors and provides benefits to society, businesses and citizens. The institutions should be underpinned by a flexible ICT-infrastructure and consider alternatives, such as the use of open source solutions.

Finally, the institutions should be fully decentralised and as close to the land rights holders as possible. Decentralised land institutions facilitate provision of land services such as registration, dispute resolution, access to land information in a timely manner, at a low cost. Provisions in the legal framework should permit involvement or co-option of legitimate persons such as credible elders, religious and opinion leaders during adjudication and dispute resolution.

5.2 Key lessons for Implementation of Fit for Purpose Land Administration in Africa

Case 1: Land Tenure Regularisation in Rwanda (Enemark, et al., 2014, p.27)

Rwanda implemented a well-functioning Land Information System through a land reform program called Land Tenure Regularisation. Nationwide systematic land registration started after piloting in 2009. The goal was to provide legally valid land documents to all rightful landholders and the program was completed in 2013. A general/visible boundaries approach was used and data were collected in a highly participatory manner. For provision of geospatial data, high-resolution orthophotos and satellite imagery was used.

Teams of locally recruited and specially trained local staff outlined the parcel boundaries on the imagery printouts that were scanned, geo-referenced and digitised. Printouts of the parcel plans became part of the legal parcel ownership document. The non-spatial data relating to owners' rights and particulars were captured in claim registers by legally constituted adjudication committees.

The information from the registers was entered into the Land Tenure Regularisation Support System, from which titles were processed and printed for first issuance. A Land Administration Information System is used for processing transactions and for updating the register. In May 2013, about 10.4 million parcels were registered and 8.8 million of printed land lease certificates had been issued. The unit costs were about 6 USD per parcel (that is of course subject to specific country conditions).

The expected achievements for Rwanda are social harmony arising from reduced land conflicts and secure tenure, increased investment in land, greater land productivity and an increased contribution of land as an economic resource towards national development.

Case 2: Systematic Land Adjudication and Demarcation in Uganda

The Government of Uganda launched a National Land Policy in 2013, which laid ground to the land rights administration framework aiming to ensure efficient, equitable and optimal utilization and management of Uganda's land resources for poverty reduction, wealth creation and overall socio-economic development. Among the several strategies to achieve this goal is systematic demarcation and certification of both individual land parcels and those of groups that subscribe to communal land ownership (Chapter 4 section 40. Alongside the National Land Policy is the Land Sector Strategic Plan [LSSP II] which also emphasizes the protection of rights through the demarcation and certification of communal land rights as well as the need to converge state and traditional systems of land administration, particularly with regard to the certification of land rights, the empowerment of decentralized institutions in land rights administration, and the management of land as a resource at the local level.

In Uganda, cadastral surveying for property definition is governed by the Survey Act of 1939, and survey regulations which set very complicated procedures for field observations, checking and compilation of cadastral maps. Cadastral surveying and processing of the final survey plan (deed-plan) to support preparation of a land title is a lengthy and expensive procedure that takes between one and six months and may cost the landowner between US $ 400 - US$ 1,300. Processing of the final certificate may cost the same amount or even more. Hence Uganda has only managed to survey and title less 20% of the land, amidst increasing cases of land grabbing. It has been reported that land disputes dominate the backlog of court cases at all levels and land is normally the cause of most criminal cases such as (murder and assault) registered at the police units (See Rugadya 2009).

The Government of Uganda, through World-bank funding implemented the Competitive Enterprise Development Project (CEDP), which resulted in establishment of a country-wide Land Information System. One of the components of the project is systematic land adjudication and certification (SLAAC) to generate 800,000 freehold titles in rural areas and 100,000 titles in peri-urban areas. SLAAC has employed a fit-for-purpose methodology as the only feasible alternative to generate the required targets. SLAAC involves the following activities:

(i.) Rapid physical planning of adjudication areas at district and sub-county level
(ii.) Mobilisation and sensitisation though radio programs and parish / village-level meetings
(iii.) Training of adjudication and mapping teams comprised of local area land committees
(iv.) Mapping of parish boundaries
(v.) Adjudication and Mapping using tablets installed with ortho-rectified aerial images at 40cm spatial resolution.
(vi.) Dispute resolution
(vii.) Compilation and display of village cadastral index maps,
(viii.) Correction of errors, and
(ix.) Processing of Title documents

Apart from the SLAAC programme, a number of other projects supported by various development partners have employed FFP LA to generate parcels and land rights information, but mainly focusing on customary land, to process certificates of customary ownership. There are over 5 NGOs and Civil Society organisations supporting government to map customary and occupancy land rights using FFP LA approach.

All the NGOs involved in land rights documentation use comparable tools for capture of land rights. The tools generally include both a mapping component for generating parcel boundaries and land rights component for capturing ownership and rights information. There is a high level of standardisation in the attributes captured by each tool given that each tool must include as a minimum, attributes defined in the standard forms that form annexes of the Land Regulations. Figure 8 shows an example of CRISP data capture tool that is being used by GIZ to map and document occupancy land rights in Central Uganda. Uganda therefore has both experience and political will to implement FFP LA as a feasible solution for securing the rights of all land owners in Uganda. However, the current efforts are scattered across various NGOs partnering with government to secure tenure rights in a peace-meal manner. In order to prepare for a national-wide project for mapping and documenting land rights for the entire country using FFP LA, the government, through funding from UN-Habitat has prepared a national strategy for implementation of FFP LA. Under the strategy, Uganda anticipates to achieve a national coverage within a period of 10 years at a cost of USD 10 per parcel.

Figure 6: CRISP Tool for Mapping and capturing land rights data in Central Uganda (Source GIZ, Mityana Project Office)

5.3 Lessons Learnt from the Experience of Rwanda and Uganda.

The two cases demonstrate that Fit for Purpose Land Administration is a feasible undertaking with potential to address long standing tenure security issues in a country. The experience in Rwanda demonstrates that a consistent and a reasonably accurate spatial framework can be established using FFP LA techniques and this can be continuously upgraded as need arises, for example during sub-division of parcels. Such a flexible system has reduced the duration of land transactions from several months to 1-4 days. The impact of land documentation has been felt in all sectors and overall, it has led to improvement of world ranking of Rwanda in the ease of doing business from 143 in 2008 to 29 in 2018 (Economics, 2019) and the 2nd in Africa, after Mauritius(Ranked as 20). Rwanda now ranks better than all the countries in the region (see table 3) in terms of easiness of doing business.

Table 3: Easy of doing business among the countries in the Eastern Africa Region

Country	**World Rank as of December 2018**
Rwanda	29
Kenya	61
Uganda	127
Tanzania	144
Ethiopia	159
Burundi	168
DRC	184
South Sudan	185

Source:https://tradingeconomics.com/country-list/ease-of-doing-business?continent=africa accessed 16th Aug 2019

Finally, the experience demonstrates that genuine political will is essential in implementing a Fit for Purpose Land administration programme at national level.

The Uganda experience slightly differs from Rwanda given that FFP LA projects are implemented by government in partnership with Civil Society Organisations. With such a diversity in the players, there is need for standardisation and coordination at the national level. Standardisation ensures that data generated from each individual project is of comparable quality and can be integrated in a national land information system. The civil society institutions formed a working group that discusses cross-cutting issues including standardisation.

Uganda has also made some attempts to incorporate rapid physical planning appraisal (RAPPA) as part of each project. RAPPA is a rapid way of undertaking *fit for purpose* physical planning to avoid delaying land adjudication and demarcation processes. In Rwanda, the approach began with titling and considered physical planning later, while updating the spatial framework. This approach ensured faster achievement of land reform goals but has presented challenges of adjusting parcels during physical planning.

The country-level approach adopted in Rwanda where the project covered all the parcels across the entire country resulted in security of tenure for all without any discrimination. It entailed an element of compulsion where all land owners were required to participate. In Uganda, the approach of scattered projects may not yield timely results in a cost effective manner given that considerable effort has to be invested in coordination, harmonisation and duplication of effort. Furthermore, the approach in Uganda is based on free prior informed consent (FPIC), which requires heavy investment in sensitisation, persuasion and mobilisation of land owners. In some cases, individual land owners may be reluctant to participate in the project. The adjudication and demarcation teams have no option but to unwilling landowners until they make up their mind. This makes the process semi-systematic/sporadic and hence more costly.

There is generally good political will to implement universal land titling in Uganda. However, successful implementation of FFP LA administration necessitates commitment and support of politicians from all divides to avoid any likelihood of conflicting messages to the landowners. Cases of negative publicity as a result of disagreements by politician have been reported for some projects in Uganda.

6.0 KEY DEMANDS FOR IMPLEMENTATION

The FFP approach aims to build countrywide land administration systems providing secure tenure for all. However, within the country context, some areas may be difficult to cover, and there may be some specific legal or institutional issues that call for further consideration. In this regard, implementation of the FFP approach should not be held back for solving some specific issues, when the major part of the country, say 80 per cent, can be covered straight forwardly using this approach. The remaining, say 20 per cent, can then be completed once the specific issues are solved. More generally, this 80/20 per cent distribution is known as the Pareto principle.

A key demand for implementation, of course, relates to developing the necessary capacity for building and maintaining the systems. It is critical to ensure that the systems can be maintained immediately and properly in terms of ongoing updating so that the systems are complete and reliable at any time. Therefore, a capacity development strategy should be adopted up front before starting the project. Another demand is about assessing the costs and establishing the budgetary base for building the systems, e.g. by seeking development aid support such as through the World Bank. And, most importantly, there is a fundamental requirement for strong political commitment and leadership for adopting the project and keeping it on the track for achieving the goals and outputs in terms of benefits for society, businesses and citizens. However, recent experiences have shown that it is possible – as shown in the case of Rwanda and Uganda above.

The FFP approach is participatory and inclusive – it is fundamentally a human rights approach. Further benefits relate to the opportunity of building appropriate systems within a relatively short time and for relatively low and affordable costs. This will enable political aims such economic growth, social equity and environmental sustainability to be better supported, pursued and achieved.

7.0 CONCLUDING REMARKS

Most developing countries are struggling to find remedies for their many land problems that are causing land conflicts, reducing economic development and preventing their countries reaching their true potential. The FFP approach provides developing countries with a new, innovative and pragmatic solution to land administration. The country specific solution is directly aligned with immediate needs, is affordable, is flexible to accommodate different types of land tenure and can be upgraded when economic or social requirements and opportunities arise. The FFP approach is highly participatory; it is quickly implemented and provides security of tenure for all. Most importantly, the FFP approach can start very quickly using a low risk entry point that requires minimal preparatory work.

The politicians and decision makers in the land sector are key in this change process and need to become advocates of change through understanding the social, environmental and economic benefits of this journey of change. This top-level support for change will then allow any barriers to changes in the legal framework and the professions to be dismantled. However, in many developing countries, land issues are highly political and controversial. Therefore, drivers for change cannot just be designed at the highest levels, but will have to be initiated through influencers at other entry points in the network of stakeholders across the land sector; and written in a language that they can understand.

The UN family of organizations has a significant role to play in this advocacy for change. GLTN will have a pivotal role in disseminating the messaging for change and providing tools to support change. The World Bank, UN-GGIM, UN-HABITAT and UN-FAO should ensure that the land administration projects they support are designed around FFP by default. The FFP approach for land administration directly supports the implementation of the VGGTs. There are opportunities for the FFP approach for land administration to be used innovatively in areas of priority for the UN, such as post-conflict situations. Support of these high profile applications of FFP will help to promote the importance and gain support for the FFP approach.

Effective capacity building is fundamental to success. Society must understand that these simpler, less expensive and participatory methods are just as effective and secure as conventional surveying methodologies. Formal organizations such as government agencies, private sector organizations and informal organizations, such as community based or voluntary organizations, need to ensure the awareness and up-to-date skills of their members and staff. Although there are short-term training needs to effect FFP approaches in land administration, there is a longer-term capacity building initiative required to create a new generation of land professionals who have deep understanding of the FFP approach to land administration and the ICT management of land.

It is hoped that the FFP approach as presented in this paper will pave the way forward towards implementing sustainable and affordable land administration systems enabling security of tenure for all and effective management of land use and natural resources. This, in turn, will facilitate economic growth, social equity, and environmental sustainability.

8.0 ACKNOWLEDGEMENT

This paper draws from a recent publication entitled “Fit-For-Purpose Land Administration – Guiding Principles for Country Implementation”, referred to as Enemark, S., McLaren, R., Lemmen, C. (2016). The publication was produced as the outcome of a project funded by UN-HABITAT/GLTN and managed by The Netherlands´ Cadastre, Land Registry and Mapping Agency (Kadaster).

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