PROCEEDINGS

of the

ENGINEERING INSTITUTION OF ZAMBIA
2021 SYMPOSIUM

Hosted by
The Engineering Institution of Zambia

Theme:
"Transformative Resilience in Times of Disruption: An Engineering Perspective"

ISBN: 978-9982-70-908-5

Friday, 16th April, 2021
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Foreword

Welcome to the Engineering Institution of Zambia (EIZ) 2021, 64th National Symposium at Avani Victoria Falls Resort, Livingstone, 16th April 2021, under the theme, **"Transformative resilience in times of disruption: An engineering perspective**". The symposium will be preceded by the Zambia Women in Engineering Conference (ZWES) on 15th April 2021 at the same venue. The symposium reflects on the effects of the COVID-19 pandemic and other disruption that are being acutely felt across all aspects of our day-to-day life and activities. This crisis will transform and leave a lasting impact on industry, business and enterprise, infrastructure and security, and on public behaviour and social attitudes. The pandemic will be experienced by all generations across the whole of society.

EIZ response to such disruption: Engineering Professionals can play a strong leadership role to identify and manage the socio-technical, economic and systemic risks, which could limit further harmful impact from this crisis, advising government on how to engineer a more resilient future.

The programme for technical papers presentations is in two sessions. All the papers in this book of proceedings were refereed through a double-blind review selection process. In addition to these parallel paper presentations, we are proud to inform that the programme includes plenary presentations, keynote presentations to be made during the opening session.

Finally, we would like to express our thanks to the authors of the technical papers and paper reviewers, whose work and dedication made it possible to put together a programme that we believe is very exciting and of interest to the engineering community and the nation at large. Personally, I wish to express my appreciation to the members of the EIZ Publications Committee for coping with the extra work load and ensuring that all the papers were ready for the symposium.

We wish you all an exciting symposium.

Eng. Prof. John Siame
Vice Chairperson, EIZ Publications Committee
April 2021

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2021 Engineering Institution of Zambia Annual Symposium
Friday 16th April 2021 - Avani Victoria Falls Resort, Livingstone, Zambia

Effects of Covid-19 Pandemic on Water Supply and Sanitation; Potential Strategies of sustainability in upcoming towns in Zambia.

Eng. Mufalo. N. Kabika[1]

ABSTRACT

The global outbreak of coronavirus disease 2019 (COVID-19) has affected the entire ecosystem of human existence. Governments including Zambian have suffered slowdown in economic activities following measures taken to control the spread of the virus. The major task is to analyze impacts on economic activities including the Water Sector. Although institutions developed response approaches, surprisingly little empirical evidence is available for robust strategies. This study used qualitative multiple case study approach to review available published literatures, data from WHO surveys and special studies in order to analyze robust strategies relevant to effects of COVID-19 on water and sanitation access. Government put a suspension on water service cut-offs and moratoriums on withdraw of service from defaulting customers' in order to increase access to water for the continued fight against the pandemic. This made the utility companies struggle to fulfill the mandate. Investment has been affected as Government has insufficient fiscal space to fund Sanitation Programs. It belabored to mitigate this through the Targeted Medium-Term Refinancing Facility (TMTRF) a facility which allows Financial Service Providers (FSPs) lend to businesses and households. Despite the facility having an initial amount of K10 billion i.e. 60 percent for targeted sectors (agriculture, manufacturing, tourism and energy) and 40 percent for other sectors. Accesses by water utility companies has not actualized owing to lurid repayment plans and collateral. Explored Potential Strategies of sustainability and implications are twofold. Firstly; engineering solutions-to completely roll out automation of operations of water and sanitation facilities to reduce cost and human interface and promote effective designs like Ultrafiltration and gravity flow decentralized systems which are highly economical. Secondly ,Non-Engineering solutions; reversal of the Suspension of cut-offs and moratoriums on water service, lobbying for increased investment and migrating from the traditional to non-traditional ventures like biogas production and reliance on Solar energy.

Keywords: Water, Sanitation, Decentralized Systems, Automation, COVID-19

1. Introduction

The current outbreak of coronavirus disease-2019 (COVID-19) first began at the end of December 2019, suspected to be from the Hunan seafood market in Wuhan City of China, and was declared

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by the World Health Organization as an international public health emergency in a couple of weeks (WHO a, 2020). In Zambia, the first two (2) cases of Covid-19 were recorded on 18th March, 2020(Tembo, 2020).According to the WHO Coronavirus Disease (COVID-19) Dashboard (WHO b 2021), Globally, as of 2nd February 2021, there have been 102,942,987 confirmed cases of COVID-19, including 2,232,233 deaths, reported to WHO. Zambia has since recorded 55,042 confirmed cases with 780 deaths. The trajectory is set to increase, necessitating Government to act to curb the spread of the pandemic. Among the restrictions imposed were on the ban of non – essential travel to all Countries and controlled movements of goods and persons across borders (Tembo, 2020) and Statutory Instrument No.22 of 2020(Public Health (Infected Areas) (Coronavirus Disease 2019).

From the water sector perspective, Government, put a suspension on water service cut-offs and moratoriums on withdraw of service for defaulting customers' in order to increase access to water for the continued fight against the pandemic (NWASCO guideline,2021). However, this has made the utility companies mandated to provide the service (Water and Sanitation Act 27 of 1997) to struggle. The water sector is paramount and the stability is non-negotiable as it comprises; water supply—the abstraction, treatment, and distribution process for treating raw water and delivering the product (drinking water) to the customer, and sanitation—the collection and treatment of wastewater so it can be safely discharged to the environment or reused as illustrated by the IFC, 2020. The challenges in the water sector are copious. The World Bank Group (2020) Policy brief notes, "As of 2017, access to an improved water source and sanitation facility stood at only 67 percent and 40 percent, respectively, with significant disparities between rural population and urban areas. Only 19 percent of rural population-less than one in five has access to improved sanitation. In urban areas, sanitation access is as low as 49 percent, a staggering proportion of Zambians (about) 19 percent still practice open defecation". The 2019 Urban and peri-Urban Water Supply and Sanitation Sector report as published by National Water Supply and Sanitation Council in table-1 illustrates a frightening situation of zero movement in National Water coverage and a 3.7 percent increase in sanitation coverage despite a notable increase in total urban population serviced with water.

Table 1: *National Urban Water Supply and Sanitation Coverage*

	2018	***2019***
Total Urban Population	7,50,180	7,328,250
Total Urban Population Serviced with water	6,114,843	6,355,754
Total Urban Population Served with Sanitation	4,449,952	4,891,719
National Urban Water Coverage	86.7%	86.7%
National Urban Sanitation Coverage	63.1%	66.8%

The suspension of water cut-offs has resulted in lost desire to settle even the outstanding water bills by customers. George et al (2020) has contended that Water utilities' operations are typically funded by customer receipts (comprising water tariffs and one-off connection charges), grants and Tariffs are often set to achieve socio-political objectives at levels that are insufficient to recover operating costs. Therefore, the water utilities require support from other sources, usually the government budget during such pandemics. The study has given a detailed analysis on the negative consequences of the COVID-19 pandemic, on the water sector and proposed possible strategies as future guidelines for operational sustainability.

2. Methodology

The study was carried out using a qualitative multiple case study approach by reviewing the available published literatures, data from WHO surveys and special studies, and different government and non-government organizations information from reports and official websites from a large number of studies. This study gives an analysis and presents robust strategies which are relevant to effects of COVID-19 on water and sanitation access.

3. Impact of Covid-19

(a) Failure to meet Investment needs: The National Water Supply and Sanitation Policy as published in July 2020 by the Ministry Water Development Sanitation and Environmental Protection (MWDSEP) has acknowledged that while the Government with support from cooperating Partners has substantially invested in the subsector, more needs to be done in order to provide required services and extend coverage to unserved areas. Inadequate investment absorption capacity partly due to procedural institutional and technical capacity, coupled with inadequate financing mechanism compounds the problem of insufficient investment in the subsector. On the other hand, The World Bank Group (2020) Policy brief notes confirms that, currently, GRZ has insufficient fiscal space to fund both the National Urban Water and Sanitation Program and the National Rural Water and Sanitation Program. For example, planned NRWSSP expenditure for 2016-20 is US$ 330 million, or US$ 66 million per year. However, the actual Ministry of Finance (MOF) allocation for rural water was only 14 million per year during the 2018-18. In addition, the budgetary allocation to Water and sanitation for the past four (4) year has presented a steady increase while 2021 has seen a reduction despite the Covid-19 effect on the sector. (figure 1)

Effort by GRZ to increase sources of financing during the pandemic has been through the Targeted Medium-Term Refinancing Facility (TMTRF) a facility which allows Financial Service Providers (FSPs) (commercial banks and non-bank financial institutions) under the supervision of the Bank, to access funds from the Bank of Zambia for on-lending to businesses and households.

The facility is not free. The Bank of Zambia (BoZ) is lending funds to Financial Service Providers (FSPs) who, when they borrow from BoZ, are obliged to on-lend to businesses and households. The facility has an initial amount of K10 billion and tenors of five (5) years for targeted sectors (agriculture, manufacturing, tourism and energy) and three (3) years for other sectors including households. FSPs will access this facility from BoZ at 12.5%.

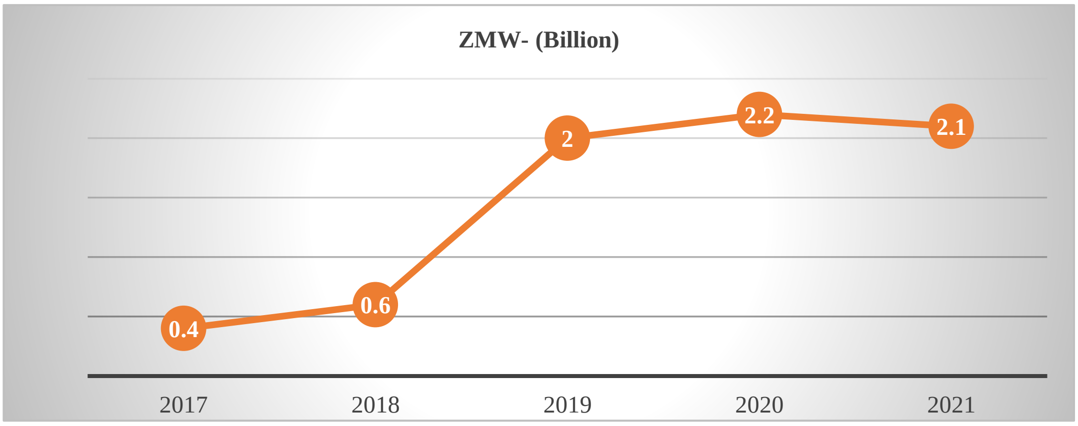


Fig 1: Budgetary allocation to Water and sanitation (courtesy National Assembly publication)

This interest rate is arrived at by taking the current Monetary Policy Rate (MPR) of11.5% and adding 1 percentage point. Further, FSPs will have a one-year grace period (moratorium) for both principal and interest payments on the facility. The facility became available for access by FSPs on April 15, 2020. For water utility companies, the facility may not be accessed despite the allocation of 40% to other sectors; as it will require clean balance sheets. This is a non-feasible undertaking as most CU have un settled statutory obligation from Zambia Revenue Authority (ZRA) and National Pensions Scheme Authority according to the 2016 report of the Parliamentary committee for parastatal bodies on the Auditor General's report .The World Bank Group (2020) Policy brief notes suggest that the NUWSSP must shift its financing focus from large infrastructure to improvement in the efficiency in Water Utility to enhance their cash flows and enable them to contribute to the capital needed to expand. This school of though is accurate on the basis of cost reduction to improve financing of the water sector. However, the ultimate solution is the adoption of decentralized systems to improve both access to water and sanitation and tackle climate Change effects.

Furthermore, according to a Rapid COVID-19 vulnerability Assessment in Lusaka, Investment in Water and Sanitation is a key strategy for the sector.

Increased investment in Water, Sanitation, and Hygiene services which are the first line of defense against COVID-19 and other waterborne diseases such as Cholera in Zambia.

The government should increase investments in WASH as the most cost effective way of addressing the COVID-19 pandemic. Scaling up investment in WASH will avert future pandemics. Government must act and ensure universal sustainable WASH services and prioritize the poorest and most marginalized, recognizing WASH as a first line of defense against future health crises.

Fig 2: Need for investment in Water and sanitation (courtesy Water Aid -Zambia)

(b) Declining industrial demand; many large users of water have economized or reduced activities resulting in a decline in demand from domestic, large commercial and industrial users due to lockdowns and travel restrictions significantly reducing revenues to Commercial utilities (Arden et al.2020).On the other hand collection efficiencies for water and sanitation services reduced and unstable due to the pandemic. Figure 3 illustrates the comparison before and during the pandemic at North Western Water and Sanitation Company.

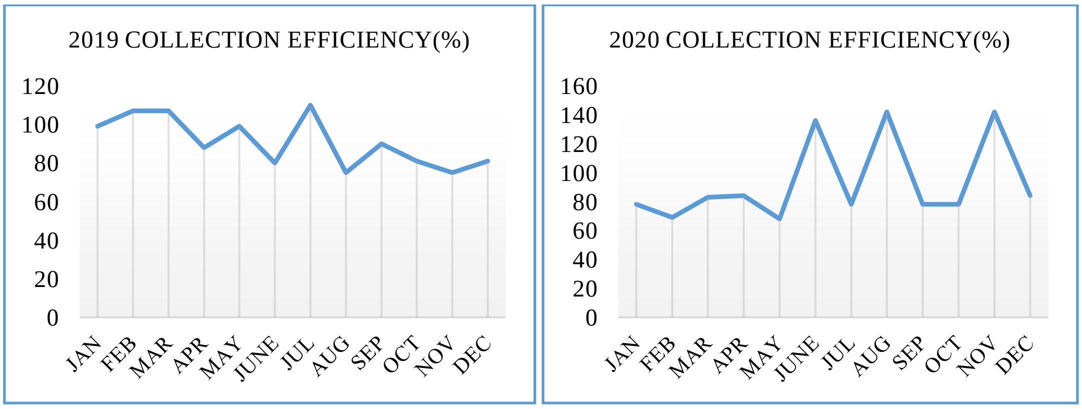


Fig 3(a) (b): Comparison of Collection Efficiency before and during covid-19 pandemic

(c) Suspension of cut-offs and moratoriums on water service: According to FIC (2020) Globally, Specific measures adopted include (a) deferments on or exemptions from utility bill payments for vulnerable groups, (b) moratoriums on cutting off the water supply (justified by the importance of hygiene in reducing the spread of the virus), and (c) suspensions of meter reading and invoicing. These measures will make the Water Utilities fail to produce water volumes required to keep the population safe against Covid-19.

4. Response to the crisis

4.1 Strategies and future guidelines for operational sustainability based on Engineering Solutions.

Engineering Solutions follow the engineering design process of identification of the problem, examining current state of issues, brainstorming the solution, development of possible solutions and creating prototype that can be tested and redesigned. For operational sustainability for the water and sanitation sector, these should include:

4.2 Automation.

Water Utility Companies should scale up the use of systems to remotely control and operate treatment plants and water supply & sewerage networks. These reduce human to human interface and perform better during any crisis. Correspondingly, automated protocols for responding to events (such as pipe bursts) will allow for effective and efficient response and a lower degree of physical interaction among staff.

Figure 4(a) (b): Automated water treatment plant for Kalumbila Mine Township in North Western Province.

4.3 Decentralized systems

Decentralized wastewater systems are a very significant strategy during and after the covid-19 Pandemic and the subsequent adoption can lead to sustainable management of water and wastewater. The Rocky Mountain Institute (2004) defines decentralized systems as an alternative to conventional, centralized systems; While Office of Water United States Environmental

Protection Agency (2005) defines decentralized wastewater systems as consisting of a wide range of onsite and cluster treatment systems that process household and commercial sewage

(a) <u>Cost implications:</u> The United Nations (2015) argues in favour of decentralized systems in that treatment facilities can be built in a piece-meal manner and does not require multi-million dollar investments that is usually difficult to raise considering the financial constraints that burden water utility companies in Zambia.

(b) <u>Comparison with centralized systems:</u> Scholars have made a Comparison between centralized and decentralized systems and results in Tables 2 below show that for sustainability and with reduced investment in the Water and Sanitation sector, decentralized systems should be adopted.

Table 2: Domènech (2010) cost and environmental impact comparison

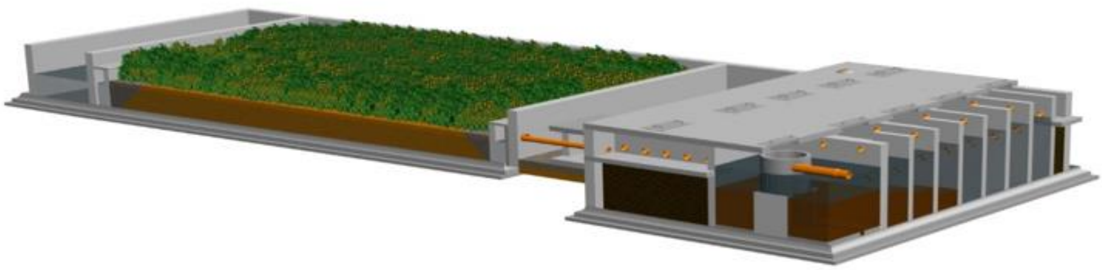
Factor	*Centralized System*	*Decentralized System*
Cost sharing	Highly subsidized.	Full cost recovery.
Environmental impacts	Environmental impacts are significant.	Environmental impacts are reduced.

Table 3: Based Chirisa (2016) Operational and Maintenance and easy of expansion

Factor	*Centralized System*	*Decentralized System*
Operation and maintenance	Full time technical staff requirements	Less demanding, can be monitored remotely
Ease of expansion	High costs, more complexity to implementation	Low cost, less complexity to implementation

Both tables illustrate that the Engineering solution in the covid-19 advent should be to decentralize WATSAN Systems. However, there are main requirements to achieve a successful adoption of decentralized technologies like**:**

(c) <u>Policy and institutional domains</u>: According to Domènech (2010) new governance arrangements Governments should play a guiding role in the promotion of decentralized technologies because they have the capacity of setting a collective learning environment and encouraging other actors to participate. Governments may also stimulate the use of these systems by developing new policies and regulations. Decentralization approach to sanitation has improved the whole WATSAN management. A project on Decentralization of septic tanks through a Community Participatory Approach yielded tremendous results in Solwezi; an urban area in the North western province of Zambia. The key phenomenon was to reduce Non-point source pollution to point source pollution which allows monitoring and management. In a City of approximately half a Million people at 95% utilization of septic tanks means 478,000 people require 80,000 septic tanks if we consider 6 persons per household. By decentralization through grouping of septic tanks, only 4000 septic tanks will be required for the same population resulting in 20% reduction in non-point pollution. Introduction of decentralized plants that covered 200 households further reduced the pollution by 30%-50% and improve Septage quality by 70%



(Jeannette et.al 2017).

Fig 5: 3-D view of the decentralized system (courtesy BORDA)

(d) <u>Examples of Decentralized system Projects include the Lumwana Mine Water Supply System:</u> The plant has five (5) compact plants operating independently; Plant 1: 18m³/hr., Plant 2: 18m³/hr., Plant 3: 18m³/hr., Plant 4: 26m³/hr., Plant 5: 60m³/hr. Total water production capacity from all the plants per hour is on average 140m³ and 3,310m³ per day. They are highly automated with all the treatment processes happening automatically. Each plant has a Programmable Logic Controller (PLC). Depending on the sensors, it is able to command for example backwashing, raising, Disludging and control some pumps. This automation has reduced staff cost, human interface and improved efficiency.

4.4 Use of renewable energy

Utilization of renewable energy lowers demand on fossil fuels like coal and oil which can play an important role in reducing the GHGs that affect the rain pattern for continued raw water abstraction from surface sources.

4.5 Wastewater treatment and reuse

Economical Decentralized Systems like the one in Kandundu-C of Solwezi –North Western Province has reduced challenges of water pollution, reuse of treated wastewater reduces the burden of excess water withdrawal from surface sources.

5. Non Engineering Solutions

These are solutions that require general,human-level intelligence,no domain expertise or deep understanding of physics,chemistry,mathematics,or mechanics like:

5.1 Re-prioritization of financing the water and Sanitation sector

Financing institutions, governments and service providers need to provide financing of the sector under the covid-19 advent. According Norman G et.al of the Water and Sanitation for the urban poor paper on six key solutions on financing water and sanitation for the poor; two major solutions are prominent: firstly, the use life-cycle costing approaches to ensure that all life-cycle costs of infrastructure and services are fully taken into account. Secondly, Maximization of local small-scale private-sector involvement in water and sanitation service provision. The second Solution is much related to decentralized systems as proposed in the sustainable engineering solutions.

Capital projects on increased water supply may be delayed, but an economic stimulus could mitigate the impact of declining revenues to fund Capex. Stakeholders and cooperating partners should seek to re-prioritize the water sector after decades of under-investment and lack of political prioritization of water and sanitation .The Bank of Zambia (BoZ)'s lending funds to Financial Service Providers (FSPs) under The Targeted Medium-Term Refinancing Facility (TMTRF)an amount of K10 billion and tenors of five(5) years for targeted sectors should have included the Water and Sanitation sector as part of priority sectors unlike only agriculture, manufacturing, tourism and energy)

6. Conclusion

The assumptions made are that, COVID -19 effects are short-term and medium term. Therefore, making strategies for the long-term benefit is paramount, as well as sustainability in water and waste water management. The entire country has been stimulated by COVID-19 pandemic and have responded triumphantly against this virus. Correspondingly, the entire human ecosystem should remain focused and develop Engineering and non-Engineering strategies as the study has illustrated. The strategies below require actualization:

Automation: As indicated, Water Utility Companies should scale up the use of systems to remotely control and operate treatment plants and water supply and sewerage networks. These reduce human to human interface and perform better during any crisis. Correspondingly, automated protocols for responding to events (such as pipe bursts) will allow for effective and efficient response, with a lower degree of physical interaction among staff.

***Use of renewable energy*:** Utilization of renewable energy lowers demand on fossil fuels like coal and oil which can play an important role in reducing the GHGs that affect the rain pattern for continued raw water abstraction from surface sources (Tanjena et al.2020). A key driver to the fight against covid-19.

Decentralized systems: The construction of decentralized System is highly economical under the Covid -19 advent; a viable option for wastewater management in upcoming urban areas like Solwezi. Based on a review of the Kandundu-C Solwezi –North Western Province System, it can be concluded that the social, financial, and environmental benefits of decentralization can mitigate the effects of Covid -19 on the Water and Sanitation sector.

Wastewater treatment and reuse: economical decentralized Systems as in Kandundu-c of Solwezi has reduced challenges of water pollution, reuse of treated wastewater domestic waste reduces the burden of excess water withdrawal from surface sources and allows more access to facilitate Covid-19 safe guidelines.

Re-prioritization of financing the water and Sanitation sector: *it has been illustrated that* Capital projects on increased water supply may be delayed, but an economic stimulus could mitigate the impact of declining revenues to fund Capex. More Stakeholders and cooperating partners should seek to re-prioritize the water sector after decades of under-investment and lack of political prioritization of water and sanitation

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Variable Speed Drive, The Workhorse of the Industry Demystified.

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Abstract

Variable Speed Drives (VSD), widely utilized in the industrial and commercial sectors are becoming the preferred motor speed controllers in a variety of operations. Notable desirable attributes of their application include energy efficient operation of industrial plant motors that result in considerable savings in electricity bills, ease of operation and for personnel safety. Despite these advantages, VSDs are however susceptible to poor power quality often causing disruption in operation. To ensure sustainable plant operation, and reduced downtime, an understanding of the VSDs working to maintenance personnel is deemed important. This paper discusses basic voltage controlled pulse modulated (PWM) VSD topology and working. It highlights PWM signal generation and switching signal duty ratio, DC full bridge converter, DC to AC inverter and finally discussing the VDS derived from the DC-AC inverter. The simplified approach adopted in the explanation makes the working principles of all VSDs clear.

Keywords: Variable Speed Drive (VSD), plant motors, Pulse Width Modulation (PWM), Duty ratio, DC-AC inverter.

1. Introduction

Variable speed drives (VSDs) applications in industrial and commercial settings are used to control the speed of AC electric motors by varying the voltage frequency supplied to the motors. In contrast to the traditional control methods, utilization of VSDs has resulted in much improved motor control, increased operational productivity and personnel safety. Their usage has also resulted in reduced downtime and reduced electricity bills compared to the traditional motor control. These improvements have been made possible by advances in semiconductor developments of power electronics. VSD systems are now finding applications in complex automation applications with interfaced computer controls. (Parzuber, 2017)

VSD comprise utility power input stage which is full wave rectified and filtered by capacitor to produce a dc voltage. Utilizing PWM switching stage, a switching signal operates high power transistors connected to the dc bus in a full bridge converter arrangement to produce high power output pulses which are the digital representation of the desired output sinusoidal signal. The

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PWM signals are generated by comparing low power sinusoidal signal to a high frequency triangular signal in a comparator circuit.

The digitized sinusoid signals in turn drive high power H-bridge transistors thereby amplifying the PWM signals which are in turn low pass filtered to recover the sine wave signal which is subsequently applied to the ac motor. The output motor speed is controlled by varying the frequency of the low power sine wave in the PWM generation section.

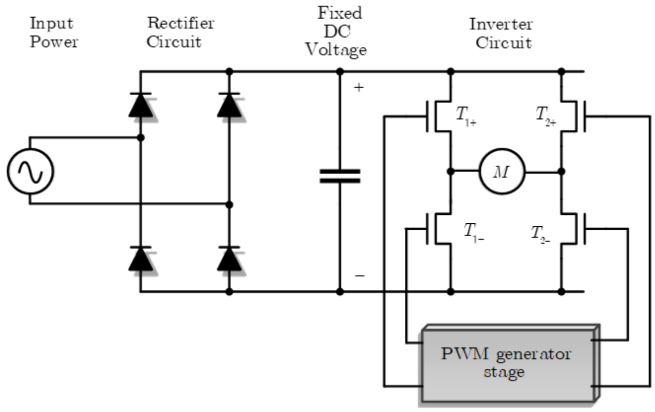


Fig.1: is a block diagram of a full bridge voltage controlled VSD comprising the input utility power stage, the rectifier, DC bus and filter capacitor and the inverter sections.

The presentation of the subject in this paper is arranged in the following order: PWM signal generation scheme is presented in section 2, full -bridge PWM signal generation scheme is presented in section 3, while the DC – AC full-bridge inverter (single Phase) is presented in section 4, followed by the explanation of the variable speed drive (VSD) in section 5 with the conclusion in section 6.

2. PWM signal generation scheme

Pulse Width modulation (PWM) is utilized in the conversion of analog signal to digital and vice versa. For voltage regulation, a desired voltage level is achieved by switching an input voltage with a defined duty ratio PWM signal as depicted in (b) of figure 2.The scheme used to derive the PWM waveform is achieved by comparing a constant DC voltage V_{contr} to a repetitive saw tooth signal V_{tri}. as depicted in (a) of figure 3.

The comparison is in such a way that when V_{contr} is greater than V_{tri}, the output signal of (b) goes high otherwise it goes low when V_{tri} is greater than V_{contr} as shown in figure 2(b). The ratio of t_{on} to period T_s is duty ratio D defined as $D = \frac{t_{on}}{T}$.

Further insight of the value of D is derived from diagram (a) of figure 2 as follows. (Franklin and Kuo, 1966)

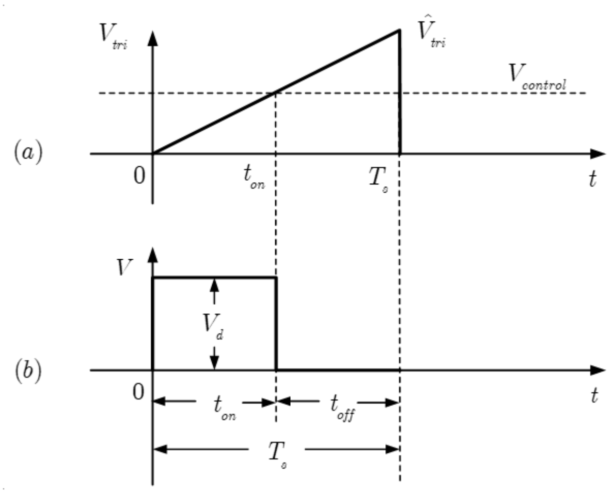


Fig. 2: Repetitive periodic saw tooth wave signal V_{tri} (a) compared to DC voltage V_{contr}, output PWM signal resulting from the comparison (b).

Between time 0 to T, the linear equation of the sawtooth scanning signal is given by

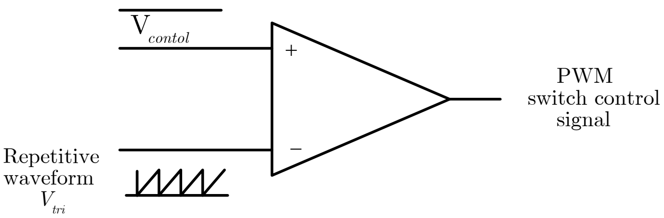
$$V_{tri} = \frac{\hat{V}}{T} t \qquad (1)$$

At $t = t_1$, $V_{tri} = V_{contr}$ making $V_{contr} = \frac{\hat{V}}{T} t_{on}$ from which duty ratio D is derived as

$$D = \frac{t_{on}}{T} = \frac{V_{contr}}{\hat{V}_{tri}} \qquad (2)$$

From equation (2) the value of duty ratio D is given as ration of V_{contr} to maximum value scanning signal V_{tri} . From equation (2), the value of D can be varied from duty ratio 0 to $\hat{V}_{tri}$ by the DC voltage V_{contr} .

The circuit shown in figure3(a) implements the above and produces a PWM switching signal shown in (b).



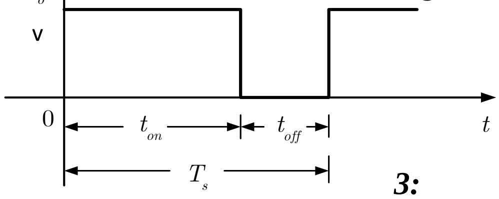


Fig. 3: PWM signal generation circuit using a comparator (a) giving an output signal (b). (Source: Mohan, et al., 2003)

When the generated PWM signal is used to set a DC voltage V_o across resistor R, specific duty ratio as shown below must be used to control the switching of switch. Depending on the duty ratio, V_o can be of any positive value between 0 and V_d .

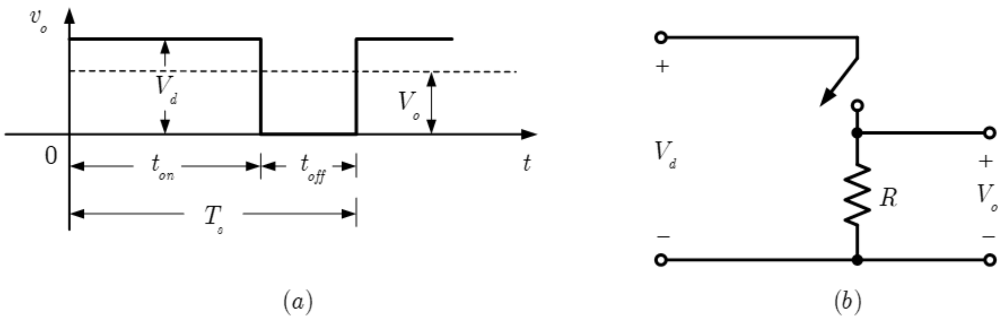


Fig. 4: (a) Simplified version of a DC-DC converter showing the switched circuit and an output voltage V_o across resistor R shown in (a) (Source: Mohan, et al., 2003)

From figure4 (a), the average voltage V_o is derived as:

$$V_o = \frac{1}{T_s}\int_0^{T_s} v_o(t)dt = \frac{1}{T_s}\left\{\int_0^{t_{on}} V_d\,dt + \int_{t_{DC}}^{T_s} 0\,dt\right\} = \frac{t_{on}}{T_s}V_d = DV_d \qquad (3)$$

Substituting for D in Eq. (3) yields

$$V_o = \frac{V_d}{\hat{V}_{st}} v_{control} = kv_{control}$$

where $k = \frac{V_d}{\hat{V}_{st}} = \text{constant}.$

Showing value of proportional to V_{contr} similar to linear amplifiers. In this arrangement, V_o can only be varied positively from zero voltage to maximum analogue value V_d .

3. Full Bridge PWM signal generation scheme

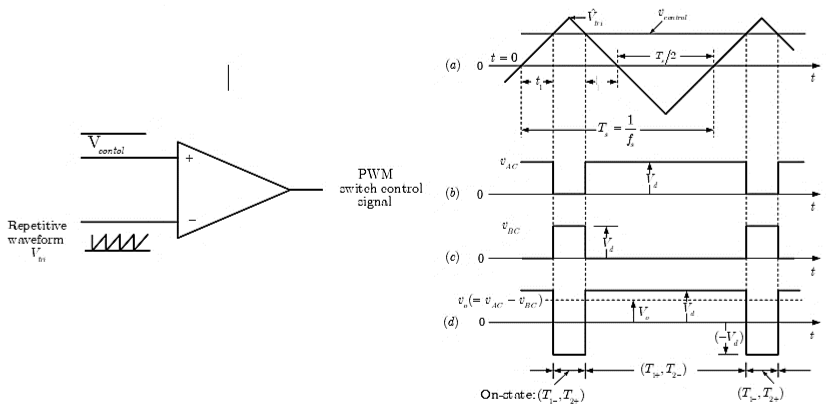


Fig. 5: PWM generation signal generation scheme: (a) signal generation circuit, (b) output PWM waveform. (Source: Mohan, et al., 2003)

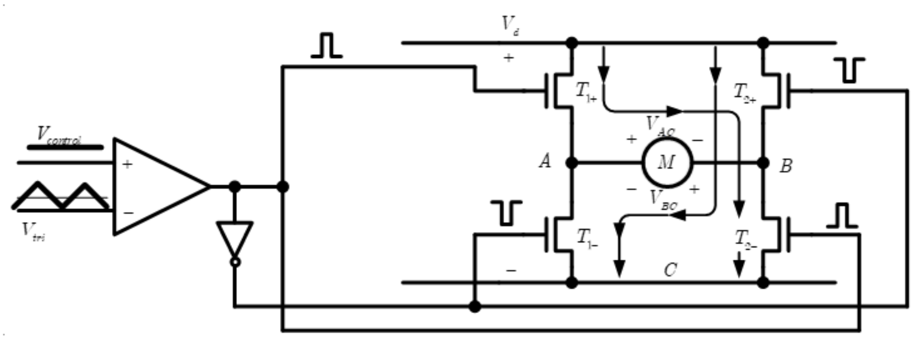


Fig. 6: Full bridge DC-DC converter circuit diagram source. (Source: Mohan, et al., 2003, modified)

To achieve reversible polarity and amplitude control of output voltage, the full bridge converter as shown in figure 6. above is employed. The PWM switching signal is derived from comparing a high frequency triangular signal waveform V_{tri} with a control voltage. as shown in figure 6. (a). Utilizing the circuit of figure5 (a), whenever $V_{control} > V_{tri}$, transistor pair $(T_{1+},\ T_{2-})$ turn on, while transistor pair ((T_{2+}, T_{1-}) is off. For this duty duration (D_1), bus voltage V_d , is impressed on the load. Whenever $V_{tri} > V_{control}$ transistor pair (T_{2+}, T_{1-}) turn on, while transistor pair $(T_{1+},\ T_{2-})$ turn off, and for this duty duration D_2 , the bus voltage is impressed on the load but in the opposite direction. The final load voltage for the period duration is determined after the evaluation of the duty ratios D_1 and D_2 ,as detailed below from the waveforms of figure5(b).

$$v_{tri} = \hat{V}_{tri}\frac{t}{T_s/4}; \qquad 0 < t < \frac{T_s}{4} \tag{4}$$

At $t = t_1$ in Figure 7, $v_{tri} = v_{control}$

At $t = t_1$ in Figure 7, $v_{tri} = v_{control}$. Therefore, from Eq. (3) it follows that

$$t_1 = \frac{v_{control}}{\hat{V}_{tri}}\frac{T_s}{4} \tag{5}$$

By meticulously observing Figure 7, it is evident that the on duration t_{on} of switch pair 1 $(T_{1+},\ T_{2-})$ is

$$t_{on} = 2t_1 + \frac{1}{2}T_s \tag{6}$$

Thus, their duty ratio from Eq. (5) is of the form

$$D_1 = \frac{t_{on}}{T_s} = \frac{1}{2}\left[1 + \frac{v_{control}}{\hat{V}_{tri}}\right]; \qquad (T_{1+}, T_{2-}) \tag{7}$$

Therefore, the duty ratio D_2 of the switch pair 2 $(T_{2+},\ T_{1-})$ is of the form

$$D_2 = 1 - D_1; \qquad (T_{2+}, T_{1-}) \tag{8}$$

Exploiting the foregoing duty ratios, we can obtain V_{AC} and V_{BC} in Figure 5. Thus, it follows that

$$V_o = V_{AC} - V_{BC} = D_1 V_d - D_2 V_d = (2D_1 - 1)V_d \tag{9}$$

Substituting D_1 from Eq. (7) into Eq. (9) yields

$$V_o = \frac{V_d}{\hat{V}_{tri}} v_{control} = k v_{control} \tag{10}$$

Equation (10) expression of the output voltage V_o for full bridge converter is same as for the simple DC_DC converter derived in equation (3). It basically states that the output voltage is an amplification of the control voltage of the PWM circuit.

4. DC – AC full Bridge inverter (single Phase)

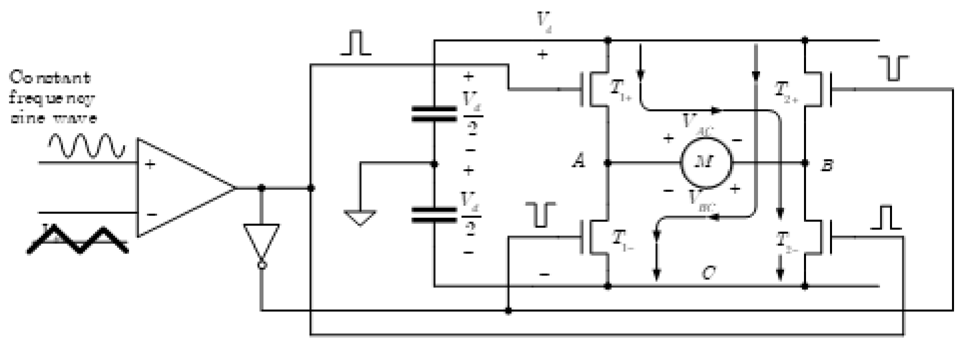


Fig. 7: Basic voltage source sinewave inverter source. (Source: Mohan, et al., 2003, modified)

The design of a sinusoidal inverter has the same procedure as discussed above in the full bridge converter. In this case the control signal ($V_{control}$) is a sinusoidal signal scanned by high enough frequency (V_{tri}) signal.

The output voltage signal is

$$V_o = \frac{\frac{V_d}{2}}{\hat{V}_{tri}} V_{control} \tag{11}$$

This expression is reordered as

$$V_o = \frac{V_{control}}{\hat{V}_{tri}} \frac{V_d}{2} \tag{12}$$

Where $V_{control} = \hat{V}_{cont} \text{ sine } \omega_1 t$ and substituting this equation in equation (12)

$$V_o = \frac{\hat{V}_{contr}}{\hat{V}_{tri}} \text{sine}\, \omega_1 t \frac{V_d}{2} \qquad (13)$$

Or

$$V_o = ma \,\text{sine}\, \omega_1 t \frac{V_d}{2} \qquad (14)$$

Where $m_a = \frac{\hat{V}_{cont}}{\hat{V}_{tri}}$, $\hat{V}_{contr}$ is maximum amplitude of the control sine wave,

ω_1 is frequency of the sine control signal.

5. Variable speed drive (VSD)

As earlier stated, discussion of the variable speed drive (VSD) in this paper will be restricted only to the basic topology, emphasizing only the PWM signal generation scheme and the Full Bridge PWM signal generation scheme from which the VSD working is derived. From the discussions of the derivation of the DC to AC full bridge above, the output voltage V_o to the load was found to be

$V_o = \frac{\hat{V}_{contr}}{\hat{V}_{tri}} \text{sine}\, \omega_1 t \frac{V_d}{2}$ expressed as $V_o = ma \,\text{sine}\, \omega_1 t \frac{V_d}{2}$ given in equation (14).

It is clear from this equation that by only varying the frequency of the comparator sine wave will equally vary the output motor input frequency. This frequency can be varied over a wide range and is independent of the utility frequency, thereby varying the speed of the motor load. The block diagram schematic of the basic VSD is as given in figure 1. above. (Mohan, *et al*., 2003)

6. Conclusion

Variable Speed Drives (VSD) are gaining popularity in high power motor speed control as high power electronic components are being developed. The work of this paper has focused on simplifying the basic voltage inverter topology by explaining the working of its' various components. Emphasis has been made on the explanation of the PWM switching signal generation and the Full Bridge converter by easy to understand circuit analysis.

Next explanation, delved in the explanation of the DC- AC inverter derived from the Full Bridge converter analysis. And finally for the simplified explanation of the VSD motor control, it has been shown that varying the frequency of the sinusoidal signal waveform in the PWM section changes the frequency of the output voltage applied to the motor, thereby changing the motor speed.

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Economic evaluation of solar PV penetration in residential microgrids using Mid-Market Rate (MMR)

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Abstract

In this paper, an economic evaluation of a Mid-Market Rate (MMR) energy trading model applied to residential on-grid connected microgrids is presented. Respect to the power sharing flexibility inherent to microgrids, the objective of this research is to determine the economic performance between MMR, a type of Peer-to-Peer (P2P) energy sharing strategy, and a traditional Business-to-Customer (B2C) model. The evaluation presented was performed from a residential microgrid context, modelled in MATLAB, having ten participants, with six being modelled as consumers while four being modelled as prosumers. All prosumers were modelled with electric Energy Storage Systems eESS while only four of the six consumers were modelled with eESS. The economic evaluation focused on annual revenue gain of prosumer and cost saving by consumer by using the two indices; Value Tapping (VT) of the local energy market and, Participation Willingness (PW) of the prosumer and consumer. Evaluation of the model showed that as solar photovoltaic (PV) penetration increases in the microgrid, annual revenue gain experienced by prosumer begin to decrease and vary inversely with the annual cost savings experienced by the consumer owing to the increasing availability of cheaper energy.

Keywords: Microgrid, Mid-Market Rate (MMR), P2P energy trading, Solar PV Penetration

1. Introduction

In the past 25 years, electricity has been the fastest growing source of final energy consumption and attracts more investment than oil and gas combined(Times, 2018). Although investment in electricity is outpacing investment in fossil fuels, the latter remains the dominant source for electricity generation, accounting for 64% of gross global electricity production in 2017((IEA), 2019). Constant improvements, however, in renewable energy generation and storage technologies have resulted in an increase in renewable energy adoption especially Solar PV. With increasing proliferation of micro Renewable Energy Systems (RES) like residential solar PV for electricity generation in developing and developed countries alike, there is an opportunity to develop a local electricity market by developing low voltage (LV) residential microgrids via aggregation of residential solar PV generators and storage

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systems(Macias and Ponce, 2006). Proliferation is fueled by a combination of technical, economical, regulatory and social factors that have created a favourable environment for RES adoption(Mah *et al.*, 2018). While the microgrids in most cases serve the obvious advantage of providing efficient, low-cost and clean electricity, additional advantages include improving operation and stability of the main local distribution grid by reducing peak demands, which can potentially offer electricity security and reliability to both microgrid participants and the main grid. Microgrids also offer opportunities to develop decentralised local energy market by designing peer-to-peer (P2P) electricity trading models with robust business models which incentivise parties to participate. Trading mechanism such as the Mid-Market Rate (MMR)(2019, Tushar *et al.*, 2019, Chao *et al.*, 2017), Supply and demand ratio(Liu *et al.*, 2017) and bill sharing(2019) have all been proven to be better than the more traditional Business-to-Customer (B2C) model(van Soest, 2018, Zhou *et al.*, 2018). Most literature on Solar PV penetration focus on the effect of penetration on power quality and system reliability. Power quality and system reliability are mainly due to, although not limited to, solar PV technologies lacking inertia (Eftekharnejad *et al.*, 2013, Kumar *et al.*, 2017), and the intermittency (McCormick and Suehrcke, 2018) and non-dispatchability of solar sources(Guizzi *et al.*, 2015). (Kumar *et al.*, 2017) discuss the implication of large-scale PV penetration to the main grid and present Low Voltage Ride Through (LVRT) and Reactive power control as impact mitigation measures. In (Limsakul *et al.*, 2014) studies are done to show increase in PV penetration result in increase in steady state voltage which agrees with (Tonkoski *et al.*, 2012) and (Canova *et al.*, 2009). (Maduranga *et al.*, 2019) identifies the effects of Solar PV penetration on the LV network and evaluate the hosting capacity of the networks. P2P electricity trading has gained popularity in recent times due to improving renewable energy technology and communication mechanisms such as the Internet-or-Things (IoT). Furthermore, the awareness and the need to have a decentralised economy has also played a major factor which has led to emergence of disruptive technologies that aim to abolish centralised control. (Troncia *et al.*, 2019) propose implementing a P2P model based on distributed ledger technology using smart contracts similar to the proposal made by (Wang *et al.*, 2019). Authors in (Zhou *et al.*, 2018) present comprehensive work on evaluation of three P2P models Bill Sharing and Mid-Market Rate (MMR). In this mechanism, the MMR price is calculated as an average of the export and import prices.

$$P_{MMR} = \frac{P^{import} + P^{export}}{2} \qquad \text{Eq.1}$$

Basing much on work done in (Zhou *et al.*, 2018, Huang *et al.*, 2020) this paper attempts to determine the economic gain by consumers and prosumers of using a MMR P2P model versus the more traditional B2C model. The evaluation is based on electricity output from the modelled microgrid at varying Solar PV penetrations. The rest of this literature is structured as follows; Section two explains the methodology and expressions used in the evaluation. Section three summaries the simulation results followed by a discussion where critical findings are highlighted. Section five is a summary explaining the research’s main contribution and areas for future research.

2. Methodology

The methodology used begins with comprehensive literature review on the effects of Solar PV penetration in microgrids (Kumar *et al.*, 2017, Kharrazi *et al.*, 2020, Canova *et al.*, 2009, Babacan *et al.*, 2018, Komušanac *et al.*, 2016, Tonkoski *et al.*, 2012, Yun Tiam and Kirschen, 2007, Maduranga *et al.*, 2019, Zahedi, 2011, Alquthami *et al.*, 2020, Singh *et al.*, 2020, Singhal, 2019) and performance evaluation of P2P energy sharing models (Zhou *et al.*, 2018, Zhou *et al.*, 2017). Authors in (Zhou et al., 2018) compare the technical and economic performance of three P2P energy sharing strategies in a multiagent framework while authors in (Zhou et al., 2017) present a general framework of evaluating the economic performance of P2P energy sharing strategies. Evaluation of the MMR model was done using the indices given by Eq. 1 to Eq. 10 and modelled using MATLAB. The MMR cost of electricity was taken as the average of the retail price (Maboshe and Chelwa, 2019) and an export price at 12.5% of retail price was assumed. The microgrid was made up of ten participants, four prosumers and six consumers All the prosumers had Solar PV with electric Energy Storage System (eESS) installed and it was assumed priority was to satisfy self-demand first, then local demand second and supply to the main grid third. Four of the six consumers had eESS that charged during the day and supplied loads during the night. The other two consumers did not have any form of supply or energy storage. It was further assumed the eESS were not used in the P2P electricity trading. It should also be noted that prosumers were modelled that they only absorb self-generated supply and not absorb any local generation from other prosumers. Consumers with eESS use the storage units to reduce importation of power from the main grid. Storage units are not used as a generation source. Loads were modelled based on actual residential demand from ten houses in the same residential area in Zambia (Northrise in Ndola, Zambia. Solar irradiation data compiled over a period of ten years (2009 to 2019) for the residential area was taken from National Aeronautical Space Agency Prediction Of Worldwide Energy Resources (NASA POWER) online repository(POWER). **Table 1** summaries the total energy consumption of residential participants and respective energy sources while **Figure 1** illustrates the solar irradiance per square meter per day in Northrise residential area.

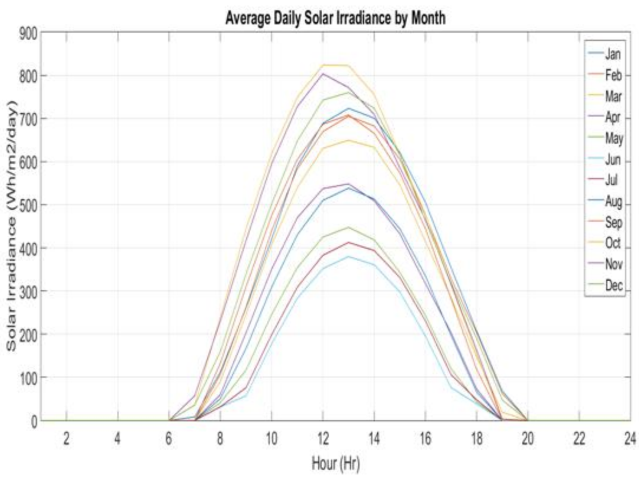

Figure 1 Average Daily Solar Irradiance by Month

Table 1 Residential site class and electricity consumption by source

Site	Class	Total demand (kWh)	PV System (kWh)	eESS (kWh)	Main grid (kWh)
No. 1	Prosumer	10.22	2.47	7.75	-
No. 2	Prosumer	13.26	3.51	9.75	-
No. 3	Prosumer	11.24	2.97	8.27	-
No. 4	Prosumer	10.90	3.71	7.19	-
No. 5	Consumer	13.31	2.51		10.80
No. 6	Consumer	14.43	3.74		10.69
No. 7	Consumer with eESS	6.62	1.80	2.66	2.16
No. 8	Consumer with eESS	7.88	1.69	3.36	2.83
No. 9	Consumer with eESS	8.19	2.89	3.43	1.87
No. 10	Consumer with eESS	8.25	2.88	4.37	1.00

The two indices used to evaluate the economic benefits of the MMR model to participants in the microgrid are, Value Tapping (VT) Index and Participation Willingness (PW) Index.

2.1.Value Tapping Index (VT Index)

This index measures the degree of local market has been realised and is mathematically expressed as:

$$VT_{index} = \frac{p^{p2p}.\sum_i^N P_{gen,i}^{bid}}{p^{retail}.\sum_j^M P_{dem,j}^{bid}} \quad \text{Eq.2}$$

Where p^{p2p} and p^{retail} are internal price and retail price in the microgrid and by the retailer respectively. The index varies between 0 and 1 with the former being minimum and the latter being the maximum.

2.2.Participation Willingness Index (PW Index)

Index explains the willingness of prosumers and consumers to participate in the P2P model based on revenue and cost saving respectively. This is summarised as follows; When the demand bid (P_{dem}^{bid}) is greater than the generation/supply bid (P_{gen}^{bid}) the net energy bid (i.e. the difference between the demand bid and generation/supply bid) is in deficit. Since the microgrid is operating in on-grid mode the deficit electricity is imported from the main grid. Equations presenting the selling price and buying price of the prosumer and consumer respectively are given by

$$p_{revenue} = p^{sell} \times \sum_i^N P_{gen,i}^{bid} = p^{p2p} \times \sum_i^N P_{gen,i}^{bid} \quad \text{Eq.3}$$

Where the p^{buy} also given by p^{p2p} is the selling price of electricity by the prosumer. Under the condition where the net energy is deficit, the selling price is at its maximum resulting in maximum revenue gain by the prosumer. Annual revenue to the prosumer is given over a period of 8,760 is:

$$p_{revenue,annaul} = \sum_t^{8760}\left(p^{p2p} \times \sum_i^N P_{gen,i}^{bid}\right)_t \quad \text{Eq.4}$$

The cost to the consumer when demand bid is greater than generation/supply bid is given in Eq.5 and Eq.6.

$$p_{cost} = p^{buy}.\left|\sum_j^M P_{dem,j}^{bid}\right| = p^{p2p} \times \sum_i^N P_{gen,i}^{bid} + \left|\left(\sum_j^M P_{dem,j}^{bid} + \sum_i^N P_{gen,i}^{bid}\right)\right| p^{retail} \quad \text{Eq.5}$$

$$p_{cost,annual} = \sum_t^{8760}\left(p^{p2p} \times \sum_i^N P_{gen,i}^{bid} + \left|\left(\sum_j^M P_{dem,j}^{bid} + \sum_i^N P_{gen,i}^{bid}\right)\right| p^{retail}\right)_t \quad \text{Eq.6}$$

When the demand bid (P_{dem}^{bid}) is lesser than the generation/supply bid (P_{gen}^{bid}), the prosumer revenue is given in Eq.7

$$p_{revenue} = p^{sell}.\sum_i^N P_{gen,i}^{bid} = p^{p2p} \times \left|\sum_j^M P_{dem,i}^{bid}\right| + \left(\sum_i^N P_{gen,i}^{bid} + \sum_j^M P_{dem,j}^{bid}\right)p^{export} \quad \text{Eq.7}$$

$$p_{revenue,annaul} = \sum_t^{8760}\left(p^{p2p} \times \left|\sum_j^M P_{dem,i}^{bid}\right| + \left(\sum_i^N P_{gen,i}^{bid} + \sum_j^M P_{dem,j}^{bid}\right)p^{export}\right)_t \quad \text{Eq.8}$$

The cost of electricity to the consumer is given in Eq.9 while its annual cost is given by Eq.10

$$p_{cost} = p^{buy} \times \left|\sum_j^M P_{dem,j}^{bid}\right| = p^{p2p} \times \left|\sum_j^M P_{dem,j}^{bid}\right| \quad \text{Eq.9}$$

$$p_{cost,annual} = \sum_t^{8760}\left(p^{p2p} \times \left|\sum_j^M P_{dem,j}^{bid}\right|\right)_t \quad \text{Eq.10}$$

p^{sell} and p^{buy} are the prosumer selling and consumer buying prices, p^{p2p} is internal price, $P_{gen,i}^{bid}$ and $P_{dem,j}^{bid}$ are the supply and demand bids of the prosumers and consumers respectively. demand and generation are taken as positive and negative respectively. p^{export} and p^{retail} are the export and retail prices between microgrid and main grid respectively.

3. Simulation Results

Table 2 Supply bid, Demand bid, cost to consumer, revenue to prosumer, buy and selling price at different penetration levels

Penetration	Annaul Energy Demand (kWh)	Annual Demand bid (kWh)	Annual Supply bid (kWh)	Consumer Buy Price ($)	Prosumer Sell Price ($)	Consumer Cost($)	Prosumer Revenue($)
0%	38,095.58	36,266.40	-	0.08000	0.045	2,901.31	-
25%	38,095.58	27,115.90	(76.47)	0.07988	0.045	2,166.60	3.44
50%	38,095.58	23,883.48	(5,741.48)	0.07061	0.045	1,709.73	258.37
75%	38,095.58	22,645.73	(13,730.69)	0.06030	0.043	1,347.12	557.71
100%	38,095.58	21,880.00	22,191.93	0.05661	0.038	1,095.17	721.15
120%	38,095.58	21,567.92	29,129.61	0.05468	0.035	965.60	832.23

Table 3 VT, EB, SS Annual revenue gain and annual cost saving gain at different penetration levels

Penetration	Installed capacity (kW)	VT index	Annual revenue gain	Annual Cost Saving
0%	-	0%	0%	0%
25%	8.40	0%	350%	0%
50%	16.50	18%	350%	11%
75%	24.90	78%	306%	26%
100%	24.90	100%	225%	37%
120%	39.90	100%	186%	44%

Table 2 present the average annual buying and selling price of electricity for the consumer and prosumer respectively, the total installed capacity, annual generation and demand from the prosumer and consumer respectively and annual cost and revenue. **Table 3** present a summary of the economic index (VT_{index}) obtained from the evaluation at different penetration levels.

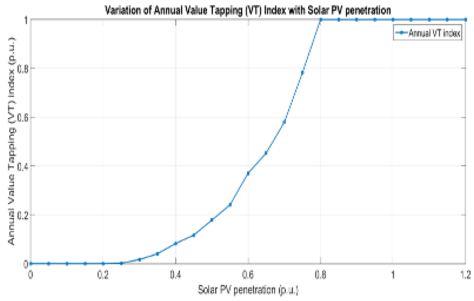

Figure 2 Variation of annual VT index with increasing solar PV penetration

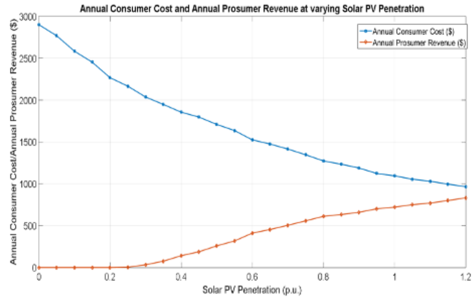

Figure 3 Variation of annual prosumer revenue and annual consumer electricity cost with solar PV penetration

Figure 2 shows annual value tapping index plot as a market share of the local energy market that is been taken by the prosumers. **Figure 3** shows how the annual consumer electricity cost and annual prosumer revenue vary with solar PV penetration.

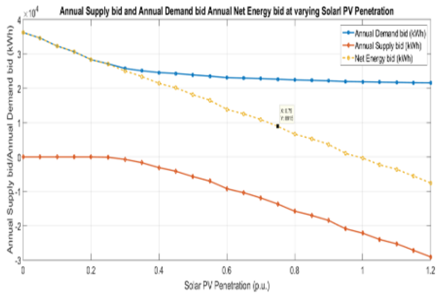

Figure 4 Variation of annual generation bid, demand bid and net energy bid with solar PV penetration

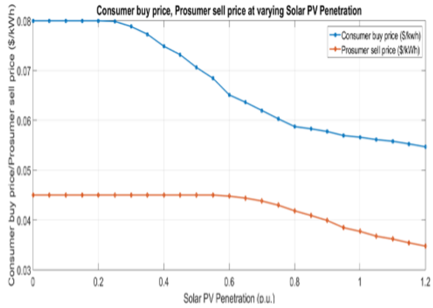

Figure 5 Variation of average consumer buy price, prosumer sell price with solar PV penetration

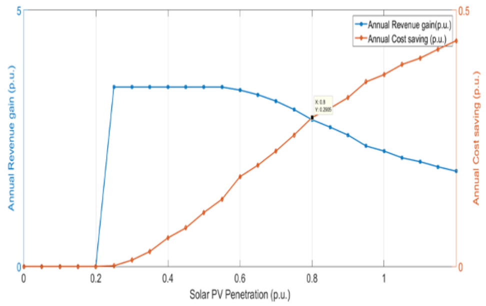

Figure 6 Annual revenue gain and Annual consumer cost saving at varying solar PV penetration

Figure 4 show plots of the annual demand bid (by consumer and prosumer), annual generation/supply bid (by prosumer), the net energy bid and how they all vary with increasing solar PV penetration. **Figure 5** shows the trend in customer electricity buying price ($/kWh) and prosumers electricity selling price ($/kWh) with varying solar PV penetration. **Figure 6** show plots of how the annual revenue gain and annual cost saving gain varies with increasing solar PV penetration in the microgrid.

4. Discussion

In **Figure 2** the VT index increases from 0% to 100% between 20% and 80% of solar PV penetration. Reason for this is, as local generation begins to increase with increasing penetration, the net energy bid begins to shift from deficit to surplus (**Figure 4**). This entitles local demand is being met by local supply reducing import from the main grid resulting in an increase in prosumer's market share of the local energy market. Furthermore, VT index occurs at 100% when solar PV penetration is at 80% because the index is being taken on an annual basis. This means at 80% penetration, revenue generated by prosumers from local generation is more than that spent by consumers if the net energy was procured at retail price from the grid. If the effects of power quality and stability in the microgrid are assumed negligible, the MMR P2P model can potentially increase the prosumer's local market share. The index also reveals the possibility of the prosumers achieving 100% market share as long as the load bid in the microgrid can be sustained. It should be noted however no additional value towards the VT index results at solar PV penetrations beyond 80%. PW index depends on how much revenue prosumers make and level consumer cost saving. The higher the revenue and saving the higher the willingness to participate for both parties. **Figure 3** shows that the inverse relationship between revenue and cost saving for prosumers and consumers respectively. The graph shows at low levels of penetration the prosumers gain on revenue is highest. When demand bid is greater than generation/supply bid the revenue of the prosumer is exclusively based on the internal selling price of $0.045/kWh. This give the prosumer the highest revenue gain as the selling price for every kWh of energy produced is being sold that the highest possible price. The consumer experiences the lowest level of saving on their annual electricity cost as only a fraction of their demand is being bought at the lower internal price of $0.045/kWh. However, with increasing penetration generation/supply bid begins to match demand bid and eventually surpass it. When generation/supply bid surpasses demand bid, excess electricity is exported to the grid. With increasing excess electricity as penetration level increases, the prosumer sells to the main grid at a much lower price, resulting in a declining revenue gain. Conversely, saving gain on electricity cost by the consumer increases. Using the equations governing PW index we can conclude that as penetration increases, the prosumer income will converge towards the export price while the consumer buying price will converge towards the internal price. It is therefore possible to reduce the cost of electricity of the consumers with the MMR P2P electricity trading model although at the expense of gain in prosumers revenue. As economics has it, the "invisible hand", will cause the number of participants reach a natural equilibrium which would result in prosumers not earning more that it affects the savings gain of the consumers.

5. Conclusion and Recommendation

The research has successfully evaluated the economic performance of the MMR P2P electricity trading model under different solar PV penetration levels. From the result trends MMR offers better economic gain than the B2C model for the consumer as PV penetration increase. This is due to increasing availability of cheaper power with increasing penetration and understanding consumers are rational agents will seek to exhaust cheap power from prosumers before receiving from the main grid. The situation with prosumers on the other hand is quite different. As penetration increases the annual revenue of the prosumers reduces. This is due to increasing supply which saturates the internal market forcing prosumers to sell at a lower price to the main grid which reduces the overall revenue. This research was done without considering the microgrid stability in terms of system voltage, system frequency, active power flow and reactive power flow at different PV penetration levels. Future research must include these stability studies.

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Reverse engineering of critical components for power generation as a strategy to a transformative resilience in times of disruption.

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Abstract

As the marketplace and manufacturing methods evolve, aging equipment and associated spare parts become increasingly difficult to obtain and may eventually become obsolete. In some cases, Reverse-Engineering Techniques can be used to facilitate replacement of existing items while minimizing the need for extensive design changes. However, risk is inherent when applying Reverse Engineering Techniques as examination of an existing specimen alone may not be sufficient to ensure that the reverse-engineered design includes provisions that address factors such as how the device functions with interfacing equipment or conditions in the installed environment. Therefore, it is important to understand the design functions of the item to which Reverse Engineering Techniques are being applied. In addition, reverse-engineered items are subject to the same types of design control considerations as other replacement items. Control of design should be documented in an appropriate evaluation.

Keywords: critical components, power generation, reverse engineering, disruption

1. Introduction

1.1. Background of the study

During the construction phase of the Power Plant Industry, equipment and components are designed using classical design engineering approaches. Designs are adopted from commercial and industrial equipment, and these designs are modified when needed for Power Generations Plants' applications and requirements. Generally, the original equipment manufacturers (OEM) are always required to keep the original design of the power plants. The absence of these OEMs suppliers force power generation utilities to undergo component level classifications/modifications in order to install new alternate replacement equipment or use of

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reverse engineering techniques to analyse, design, and manufacture replacement critical components for existing equipment.

Currently, the Power Generation Services (PGS) perform reverse engineering at a very lower scale for the components that are not regarded as critical components in terms of classification. The cause being lack of a strategical support from executive management, and this led to PGS depending more on the overseas market for procurement of these critical components. As a routine, PGS always import material and finished product from abroad, and due date delivery of such components takes an exceptionally long period to arrive in the country (South Africa). This delay leads into production loss since the power plants will not be in operation. From an economical point of view, PGS is spending millions of rands through importing of power plant critical components and various products while such critical components can be reverse engineered and manufactured locally.

Critical components are items of high risk where the consequences of failure, directly or indirectly have an unaccepted high impact on the project feasibility or negatively impact the image of the organisation. The components that are classified as critical are as follows, namely: Turbine Casings, Compressor Casings, High Pressure (HP) -Intermediate Pressure (IP) and Bypass Valve Casings, as well as turbine and compressor gland boxes. Furthermore, the components that categorised as critical are those that are operating in the following conditions: (i) temperature exceeding 120°C and stress exceeding 100 MPa for periods lasting more than 1000 hours and (ii) turbine components that have an unacceptable high rate of erosion or corrosion are also critical, namely: blades, shrouding, glands segments and valve seats.

1.2. Rationale and Scope of the study

The scope of this study takes into consideration the literature study which incorporated the investigation of the Reverse Engineering of critical components for power generation as a strategy to a transformative resilience in times of disruption.as well as the challenges faced by the PGS regarding procurement of these components. As we are all aware of the current status quo regarding the pandemic known as COVID-19, the Power Plants in South Africa are operating at severe pressure where the Power utilities end up shedding the load due to failures and maintenance schedules as well as lack of components replacement. The goal of a successful Reverse Engineering project is to produce information that is sufficient to duplicate an item, which may result in ownership of the equipment design and the design control process being transferred to the utility. This paper provides an overview of the Reverse Engineering of critical components as a strategy during times of disruption within PGS, in South Africa. Below is the map representing South Africa.

1.3. Aim and objective of the study.

The aim of this study is to report in a form of summary of Reverse Engineering of critical components for power generation as a strategy in times of disruption and provide guidelines for considerations while making a case for the need for Reverse Engineering of critical components to derive a framework required in the power generation plants.

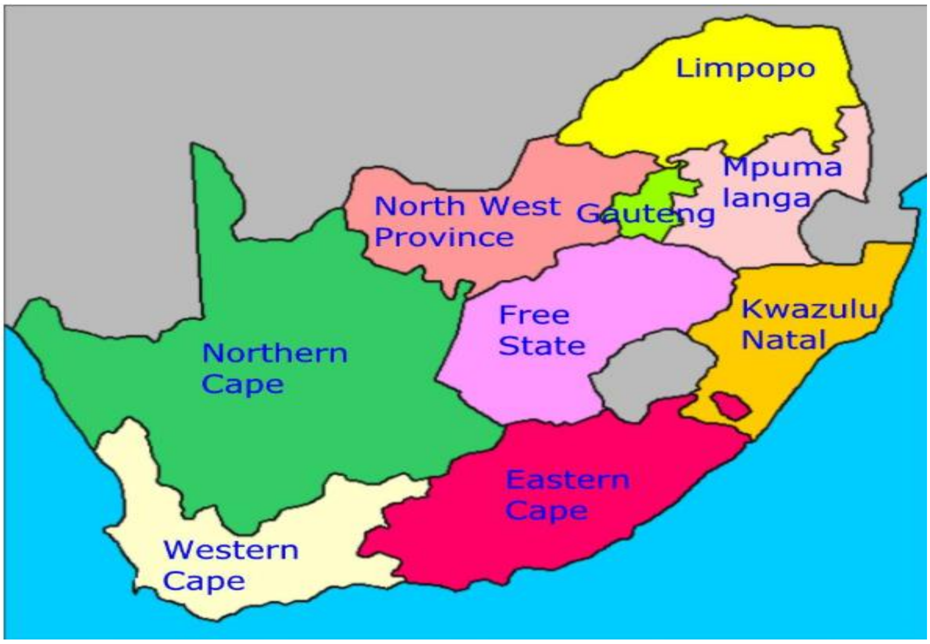

Figure 1 : Represents the South African footprint
(Source: https://www.southafrica.to/provinces/provinces.htm)

2. Literature Review

Zhang and Zhou (2016 :213) stated that forward engineering is the process that moves from high-level conceptualisations, logical, and implementation designs to the physical implementation/ commercial utilization whereas Reverse Engineering (RE) categorically interrelate well with forward engineering. Generally, forward engineering has a significant contribution to output and commercialization innovation than reverse engineering. Moreover, Zhang and Zhou (2016 :214) implies that by comparison, RE functions on innovation output is mainly through indirect effect, which intensifies the role of forward engineering by providing the knowledge base for novel research and development (R&D) activity. Epri(2018 :4) defined reverse engineering (RE) as an organisation concept from tendering, design, manufacturing to product delivery. Components that appear to be technically simple may lead into a serious problem e.g. complex material compositions, heat treatment, and manufacturing technique or fulfil secondary purpose in a plant system, which are obvious from casual examination. Failure to identify these and other important features can result in premature component failure and this will lead into catastrophic. Anwer and Mathieu (2016 :168) asserted that with regards to mechanical engineering design concept, RE is a procedure that starts the redesigning process where a component is inspected, dismantled, investigated, tested, and documented with regards to its functionality and manufacturability as well as assembling.

According to Anwer and Mathieu (2016:165) RE is acknowledged as a crucial matter in component design process that focusses on reverse techniques, assumption and discovery in design. Moreover, Anwer and Mathieu, 2016 stated that reverse engineering in regard of mechanical engineering, has grown from recording technical component information, and to establishing manual re-design process. According to Anwer and Mathieu (2016:67) RE of mechanical components is mainly approached in application and literature review from a geometric point of view. Geometric reverse engineering encompasses mesh segmentation, surface reconstruction, and feature recognition. Furthermore, nowadays it supported by a digital stand and computer aided design models.

Epri (2018 :7) implies that reverse engineering of an electrical and electronic components and items presents unique situations that require special consideration. Since it is well known that primary requirements for reverse engineering is due to obsolescence and the recurring introduction of new technologies. Most electrical and electronic reverse-engineering projects result in design upgrades because the discrete electronic components available for use in the replacement employ current technologies. Bauer *et al.*(2019 :66) stated that exchanging broken or worn-out critical components within power generation services is costly and time-consuming activity which could be resolved by supplying needed spares components within due date delivery in order to cut down predetermined breakdowns. Moreover, Bauer *et al.* (2019 :68) implies that maintenance work is always delayed due to unavailability of simply accessible components design drawings/information, which leads to holding up for older items or using ones from other original equipment manufacturers. Now reverse engineering is seen as a solution since an accurate geometrical feature of the product can be attained with comparatively less attempt.

(Zhang and Zhou, 2016 :213) stated that the ethicality and legitimacy of RE performed by China is often condemned by industrialized economies, because this always leads to imitations and even counterfeits, which affect the overseas original designers. Since China is regarded as a technology follower, it has implemented a catch-up strategy and narrow the technology gap. Furthermore, Zhang and Zhou (2016 : 213) implies that as technological followers, china usually does not strictly enforce the intellectual property right. As legal constraint being low, corporates are more likely to invest in RE. Due to intellectual property infringements, products from China are usually banned in the international trade. Regardless of infringement and counterfeiting that violate technological development ethics, china has learned a lot in technology through RE concept.

3. Methodology

This paper aims to provide guidelines (business, legal and technical perspective) for considerations during Reverse Engineering of critical components for power generation as a contributive strategy to a transformative resilience in times of disruption while making a case for the need for Reverse Engineering to derive a framework of critical components required in the power generation plants. The other sources of information considered in this study are as follows:

- Maintenance management and engineering manuals
- Production and operations management
- System engineering and management manuals
- Technology management manuals

In this paper, the approach incorporates activities associated with the key word, Reverse Engineering as shown in table 1 below.

Table 1: Represents activities associated with the term reverse engineering.

Source: (extracted from Epri, 2018:5)

Activity	**Purchase an item with known attributes or design from a different supplier**	**Recover characteristic information for dedication**	**Produce a functionally equivalent "part" (simple item)**	**Produce a functionally equivalent "component" (complex item)**
Description	• Capturing information that is necessary about an item to create a purchase specification. • Examining a standard product or its specification to identify information needed to purchase it directly from a manufacturer or alternate source. • Purchasing an item directly from a manufacturer or alternate source.	• Examining a specimen to identify acceptance criteria/characteristics pursuant to the commercial grade dedication process.	• Recovering information about a part so that a functionally equivalent part can be fabricated and installed in existing equipment.	• Recovering information about a component so that a functionally equivalent component can be fabricated and installed in existing equipment.
Purpose	• Expanding supplier options, reduce cost or lead time.	• Recovering information about the item's original design characteristics to help establish acceptance criteria.	• Recovering information about the item's original design so that a fully functional replacement can be fabricated.	• Recovering information about the component's original design so that a fully functional replacement can be fabricated.
Example	• Recovering information about a fastener, O-ring, or drive belt so that it can be purchased from a different source.	• Using Fourier transform infrared spectroscopy (FTIR) to determine material type. • Examining surface finish to determine machining process used to fabricate.	• Recovering dimensional and material information from an existing motor-operated valve stem nut and creating drawings so that a machine shop can create a replacement.	• Recovering dimensional, material and functional information from an existing circuit card, prototyping and fabricating a replacement.
Conditions/ Boundaries	• Items are fabricated in accordance with standards or known design parameters.	• The information is used for commercial grade dedication.	• The item is simple in design requiring only dimensional and material of construction information.	• The component is complex in design; multiple parts must interface to achieve function.
Design	• Same design.	• Same design.	• Functionally equivalent or new design.	• Functionally equivalent or new design. • Consider system design basis information if available.

4. Results

The analysis of results as presented in figure 2 below, indicate that the author needs to conduct further research in order to expand the topic key words as mentioned above and that various subjects should be incorporated with regards to Reverse Engineering of critical components in times of disruption. As a routine, power generation services (PGS) always import material and finished product from abroad, and due date delivery of such components takes an exceptionally long period to arrive in the country (South Africa). This delay leads to production loss since the power plants will not be in operation. The developed conceptual framework in figure 2 below is intended to resolve the problem that the country is encountering today which is the worst case.

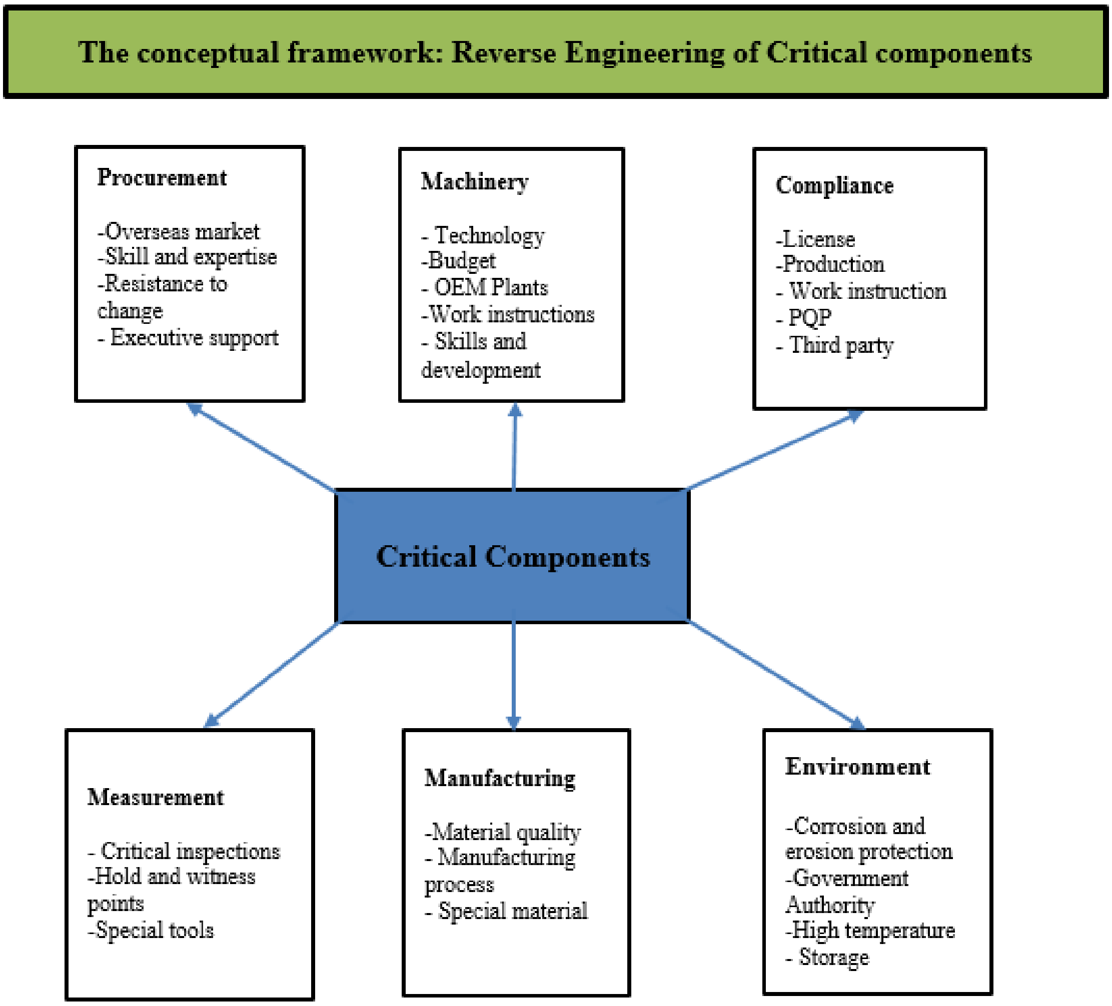

Figure 2: Developed Conceptual Framework of Reverse Engineering

5. Discussion

It is evident from research perspective that there are few countries that understand the reverse engineering concept. The lack of top management interest/ technical know-how is currently destroying the PGS in terms of procurement of critical spares abroad since there are no proper research and development models/structures. Due to long lead procurement of critical components from abroad while we can reverse engineer and manufacture the components locally, today South Africa is experiencing a hard load shedding which is having an impact on our economy. Furthermore, as the world has been struck by the COVID-19, the developing countries find it difficult to keep the lights on since we are relying more into overseas markets and experts to maintain our power plants.

6. Conclusion and Recommendation

Based on the information presented in this study, it is recommended that the Power utilities and South African Government work together on how to address the Copy right Act No.78 of 1978 and amend it accordingly since it only focuses on artistic works not engineering/manufacturing work. To reduce the long delays procurement of critical components and reduction of load, the power utility and government should empower its employees with required skill to ensure that mass production and manufacturing should take place within the country. Africa as a continent has reputable universities that are producing quality engineers that are competing world-wide.

Acknowledgements and declaration of conflict of interest

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Biographies

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Antoine F. Mulaba-Bafubiandi served for more than two terms as Head of School of Mining, Metallurgy and Chemical Engineering at the Faculty of Engineering and the Built Environment of the University of Johannesburg, South Africa. He is a (full) professor in hydrometallurgy who served in the industry for more than 20 years while 35 years in academia. He has supervised and graduated Doctorate and Master's degree students as well as numerous B-Tech and B. Eng (Hon). students. He has a PhD in Engineering, from KULeuven (Belgium), M.Eng., Lic. Physics (5 years) and an MBA. His research interest include circular economy, green production, technology management, sustainable production, water treatment and management, waste to energy, disruptive technologies , strategy, change management and industry symbiosis.

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Diversification and repositioning as a resilience strategy for sugar cane Industry in South Africa after implementing a tax on sugar-containing beverages.

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Abstract

South African sugar industry is facing a major decline in sugar demand. Exacerbated by the use of organics and alternatives, the decline in demand is due to a global decrease in sugar consumption and the introduction of the health promotion levy (HPL) and tax on sugar beverages. As a result, the South African Sugar Association (SASA) has turned to the government to develop the rescue plan of finding new income streams for the industry. Such a rescue plan involves diversification into the energy market. This paper outlines different pathways that the Sugar cane industry can use to diversify its dwindling income and demonstrate a resilient survival. This paper is based on a desktop literature review to discuss possible income streams to ensure the sugar cane industry's survival. Applications like electricity generation and ethanol production, use of different, alternative and appropriate new technologies. The outcome of the research showed that Brazil has a resilient sugar industry, which was created by cogeneration and production of ethanol. South Africa has enough land to plough sugarcane, there is a potential to revive its industry through cogeneration and ethanol production. However, the current South African mills technologies needs to be upgraded and improve efficiency to export electricity to the grid.

Keywords: sugar cane industry, energy production, ethanol production, cogeneration, resilience, policies

1. Introduction

The South African sugar industry is regarded as one of the world's leading cost-competitive producers of high-quality sugar and creates employment (SASA, 2019). South African Sugar Industry has six milling companies with 14 sugar mills across South Africa (SA), with Kwazulu-Natal and Mpumalanga having 21926 registered sugarcane growers (SASA, 2019). South African Sugar Industry was described as "Being in the intensive Care Unit". About, 60% of South African Sugar is traded in the South African Customs Union (SACU), and the remainder is exported to Africa, Asia and the Middle East. After implementing a tax on sugar-containing beverages, 250 000 tons of sales were lost during the first year, with a loss of R1.2-billion in revenue (South

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African Sugar Association, 2019). The objective of this paper will be based on a desktop literature review to discuss possible income streams to ensure the sugar cane industry's survival. Applications like electricity generation and ethanol production, use of different, alternative and appropriate new technologies.

2. Sugarcane Processing

Production of sugar from sugarcane consists of several processes: Extraction, clarification, evaporation, crystallization and drying. During the extraction process, the sugar cane is squashed to produce draft juice and bagasse (Dogbe, Mandegari and Görgens, 2018). The bagasse is then taken to the steam boiler. The draft juice is taken through the clarification process to produce clear juice. The clear juice is taken to the evaporation process to produce syrup which will be taken to the crystallization process to produce raw sugar (Dogbe, Mandegari and Görgens, 2018). The raw sugar is dried and packaged into different sizes for the customers. The summary of the sugar production process is illustrated in Figure 1.

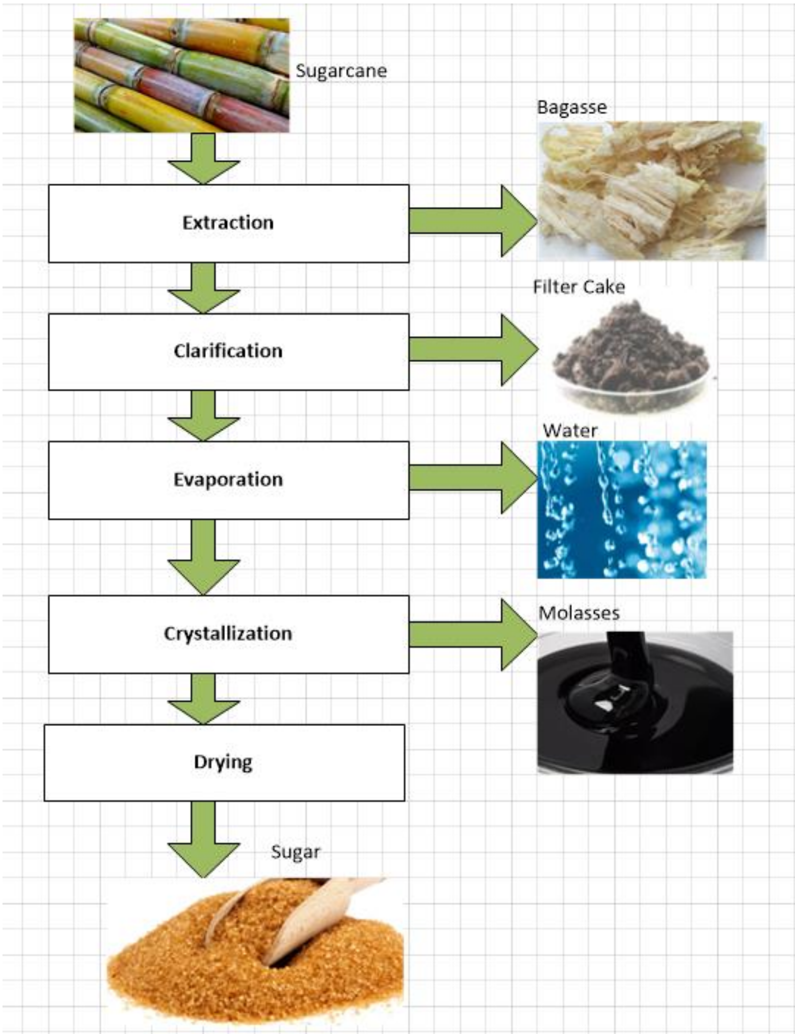

Figure 1 Sugar cane process (Dogbe, Mandegari and Görgens, 2018)

3. Sugarcane processing by-products

Sugarcane can produce different products such as sugar, bagasse, electricity, steam and ethanol.

3.1 Sugar

Sugar is produced after the extraction, clarification, evaporation, crystallisation processes. The sugar produced can be white or brown.

3.2 Bagasse

Bagasse is the remaining pulp left after extracting the juice from the sugarcane.

The Felixton II sugarcane mill in Empangeni uses only 50% of its bagasse to generate steam and electricity, as a result of its energy-efficient design (Williams, 1986). In South Africa, the Illovo Company uses bagasse as a bio-renewable fuel source to produce steam and electricity to assist in the sugar processing machines (ILLOVO Sugar Company, 2019).

3.3 Electricity

Electricity is produced by burning bagasse in the Sugarcane Mills. The key in bagasse cogeneration is steam-Rankine cycle design (Salman, 2020). The bagasse is fed into a large furnace to generate steam in a boiler with a typical pressure of more than 40 bars and a temperature of 440°C(Salman, 2020). The high-pressure steam is then expanded in double extraction condensing type turbo generator. Higher-pressure steam, gets generated in the turbine–generator set and more electricity is produced for the sugarcane milling process. The excess electricity generated in the turbine generator set is then fed into the grid(Salman, 2020).

South African sugar mills currently generate electricity for their consumption, thus showing that there's a potential to generate electricity using bagasse and supply the surrounding towns. With such, they will be reducing the ESKOM challenges of having too much electricity demand than supply. In 2013/14, about 90% of the Illovo's sugarcane processing machine electricity requirements were met through cogeneration. Electricity is also utilised to produce hydrogen by electrolysing water. The hydrogen was used as a catalyst to convert furfural to furfural alcohol (ILLOVO Sugar Company, 2019).

3.4 Steam

Steam is produced by burning bagasse. The steam generated in the sugarcane mills is used during the clarification, evaporation and crystallisation processes. An increase in steam production can lead to steam exportation to distillery industries; this will bring profit to the sugar mills. However, the environmental impacts of the steam generated will have to be taken into consideration. Steam is used in steam-heated factories and steam-driven turbines in power plants (TLV, 2020).

3.5 Molasses

Molasses is a dark brown juice obtained from raw sugar during the sugarcane processing. Illovo ferments molasses and purifies it to produce drinkable alcohol for use as a neutral spirit for beverages and spirits for pharmaceuticals and other industries (ILLOVO Sugar Company, 2019)

4. Sugarcane Technologies

Annexed and Autonomous are technologies that are used to produce sugar and other by-products in Brazil mills.

4.1 Annexed distilleries

Brazil uses annexed distilleries, and ethanol is one of the by-products. Where 50% of the sugarcane is diverted to sugar and ethanol production. Bagasse is utilised during the steam process. The electricity produced can be used in the mills, and the surplus electricity can be sold to the grid (Cavalett *et al.*, 2011). The **Error! Reference source not found.** below shows the annexed plant flow sheet. Annexed technology can be used for cogeneration.

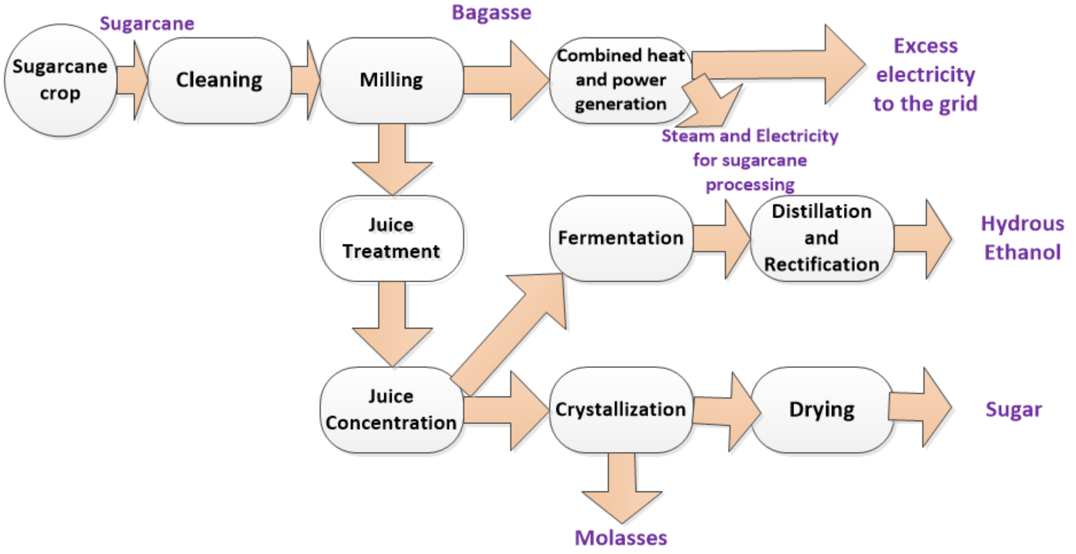

Figure 2 Annexed plant flowsheet (Cavalett et al., 2011)

4.2 Autonomous distilleries

Autonomous distilleries are the latest technology, where all the sugarcane is used for ethanol production. Bagasse is utilised during the steam process electricity demand in the mill. The excess electricity can be sold to the grid (Cavalett *et al.*, 2011).

4.3 Comparison of Autonomous and annexed distilleries

It is not possible to establish significant differences between Autonomous and annexed distilleries. A comparison study between the two distilleries was conducted, and an optimised scenario shows that the Autonomous plant presents a higher Internal Rate of Return (IRR) than annexed. (Cavalett *et al.*, 2011).

5. Cogeneration in Sugar cane Industries

Cogeneration is defined as generating steam and electricity in a single power plant (Mbohwa and Fukuda, 2003).

5.1 Cogeneration in Hawaii and Mauritius

The bagasse cogeneration was pioneered in Hawaii and Mauritius. In 1926/27, 10% Hawaii and 26% Mauritius electricity generation were from sugar mills. A typical diagram, which illustrates how cogeneration takes place in the sugar mills is given in figure 3. (Birru, 2016)

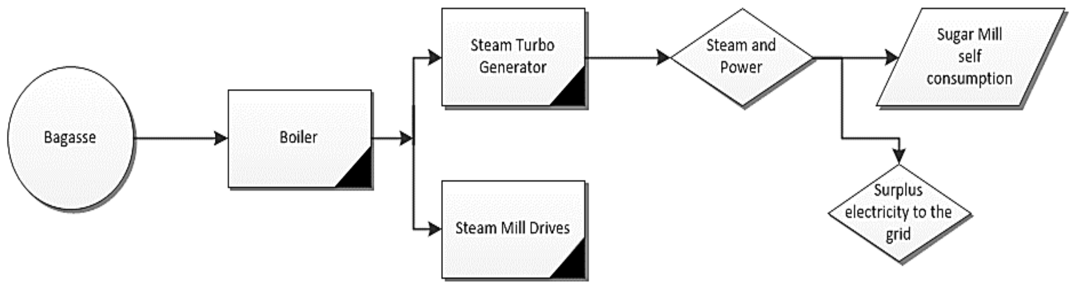

Figure 3 Cogeneration process using bagasse in sugar mills (Birru, 2016)

Traditional sugar mills without the capability to export electricity to the grid generate 10 – 20kWh electrical energy and consume 480-550 kg of steam (Birru, 2016). In comparison, the modern sugar mills with efficient cogeneration system installation generate electrical energy of 115-120kWh (Birru, 2016). The South African sugar mills are still using traditional technology, which produces electricity for self-consumption. However, to partake in cogeneration, modern technology needs to be installed. The modern technology capacity will differ per sugar mill, since their demand and sugarcane capacity differs.

5.2 Brazil Sugar industry

The sugar Industry stands out on electrical energy production in the Brazilian energy Mix. After updating Law 9,427, it increased the limit of power injected in the transmission/distribution systems of existing projects from 30 to 50 MW. This led to an increase in cogeneration projects' implementation(Santo, 2020). Brazil is the world's second largest ethanol production(Wikipedia, 2021). During the 2008/2009 harvest, it was anticipated that 44% of sugarcane would be used for sugar, 1% for alcoholic beverages and 55% for ethanol production(Wikipedia, 2021). Unfortunately due to COVID-19 , there was 40% drop in the price of hydrous ethanol from February to April 2020 (Vinicious, 2020).

6. South African Policies on Renewable energy

The White Paper on Energy Policy encourages multiple players' entry into the energy generation market (Department of Energy *et al.*, 2015). The Sugar Production Industry is allowed to produce electricity for trading; however, it needs to be registered with NERSA. Through the Electricity Act, the National Electricity Regulator (NER) has jurisdiction over the entire Energy industry and regulates market access by licensing all producers that produce more than 5 GWh per annum

(Government Gazzette, 2006). Since the Sugarcane Industry can produce ethanol, The Gas act and Amended Petroleum Product Acts need to be considered. The Gas Act (Act 48 of 2001) and amended the Petroleum Products Act provide a basis for integrating renewable energy obtained from biodiesel, ethanol and landfill gas into the gas and petroleum industry regulatory framework.

7. Conclusion

The Brazilian sugarcane industry has shown significant resilience through cogeneration and the production of ethanol. Since South Africa has enough land to plough sugarcane, there is a potential to revive its industry through cogeneration and ethanol production. However, the current South African mills technology needs to be upgraded and improve efficiency to export electricity to the grid and increase the production of ethanol.

8. Next Steps

A thorough Resource Assessment will be conducted to analyse the South African potential to generate ethanol and other by-products from sugarcane. The facts and figures of land available, sugar cane crushed, bagasse, steam, electricity for self-consumption and trade, biogas, and ethanol will be used to model different scenarios using VEDA-TIMES software. The study to determine if the sugarcane Industry is sustainable or not will be conducted.

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Author's contributions

Unarine Mudau: thought of the research, write up. Antoine F. Mulaba-Bafubiandi: created the opportunity, Redesigned the research focus, crystallized the formulation of the research, write up and quality assurance. Mamahloko Senatla: created a platform to use VEDA-TIMES software, redesigned the research's modelling methodology and quality.

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Energy Technology Scenarios for the Future: Lessons from the Developed World

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Abstract

Accurate forecasting of energy needs is faced with many challenges due to the complexity of its qualitative influence parameters. Energy scenario foresights are expected to consider these various parameters as they are an integral part of future energy prices and technologies in developing countries such as Zambia. Future prices regarding energy are expected to face similar external trends as present ones. This means that they are likely to experience similar day to day challenges. Energy technologies may not be commercialised because of regulatory, economic, performance, organizational, market or a combination of any two or more of these classifications. The fact that some of these parameters can be reasonably quantified implies that reference could be made from experiences and challenges faced in developed countries such as Scotland. Most energy scenarios that consist of different energy source mixes are designed to give the same energy service whether it is lighting, cooking, space heating, water heating or refrigeration as few examples. Case studies have however proven that these services could also be misused if efficiency of the energy delivery service is improved. Therefore, it will take more than just improving efficiency to ensure that grids in developing countries like Zambia are made stable. Most energy scenarios have lots of uncertainty due to the reliance of resource data for different sources on past data. This means that additional energy buffers are necessary even when the developed energy source mix meets the targeted demand. For Zambia, the dominance of hydropower and biofuels in the country's energy mix prompts the need to pursue additional energy buffers through enhanced diversification in other energy sources such as solar, geothermal, and wind.

Keywords: Energy Needs, Energy Scenario Foresights, Future Energy Prices, Energy Technologies, Energy Mix.

1. Introduction

Energy scenarios for future consumption need to be developed to meet current energy deficits in Zambia. Electric supply needs to exceed demand to ensure that energy needs are always met. Computational modelling may be used to show how energy balances when there is insufficient supply in different scenarios as well as when there is excess supply.

We are in the midst of an energy revolution. Many factors such as economic landscape, developments in technology, evolving business models and consumer behaviour are changing at an unprecedented rate creating more opportunities than ever for our industry (NationalGrid,

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2020). Multiple qualitative parameters may heavily influence future energy scenarios. The most prominent parameters have been discussed in this paper.

2. Qualitative Parameters

In this research, 2016 is considered to be the baseline year of these qualitative parameters while 2025 will be the projection limit. The parameters discussed in this paper provide an insight of past and present events that may influence Zambia's energy sector for the 10-year period considered here. This 10-year period was analysed by considering the following qualitative parameters:

2.1 Natural Catastrophes

The impact of natural catastrophes on energy technologies can be devastating. A classic example is the tsunami which was brought about by the Tōhoku earthquake on 11th March 2011 (Kessides and Toman, 2011). It affected power production at the Fukushima Daiichi power plant. According to Kessides and Toman (2011), the disaster affected both economic and energy stability on not only Japan but also the World.

The increased occurrence of droughts expected due to climate change effects (NOAA, 2021) may further affect Zambia's dependence on hydropower. This has the potential to affect regional electricity interconnections in the Southern Africa Power Pool (SAPP) thereby resulting in possible electricity deficits in neighbouring countries as well. This prompts the need to invest in more drought resilient renewable energy sources like solar photovoltaic technology.

2.2 Cultural Acceptability

Energy transition difficulties due to cultural acceptability are common. According to MacKay (2009), it is necessary to respect other people's culture without having to enforce what people from other cultures believe in. His findings concluded that people in England were willing to switch from fossil fuel powered automobiles to electric ones if their car appearance did not change drastically (MacKay, 2009). This willingness is expected to reduce the price of fossil fuels should electric cars be developed and made relatively affordable by 2025.

In Zambia, a 1 MW hydropower plant was developed in Shiwa Ngandu but residents in the area only consume less than 300 KW of electricity. This implied that locals preferred to not connect to the grid despite having a World Bank funded grid connection subsidy in place (PMRC, 2018).

2.3 Environmental Taxation

The climate change debate has led to the need for the World to reduce greenhouse gases (GHG) air pollution. This has seen a variation of energy technology prices especially among the Organisation for Economic Co-operation and Development (OECD) countries with regards to emission intensities (Hoeller and Wallin, 1991). Past and current typical trends are therefore expected to carry on until 2025, the projected end line year for this research.

According to EDF (2020), the economic benefits from reducing carbon dioxide emissions can be enormous. The United States of America Environmental Protection Agency (USAEPA) has projected the value of climate pollution mitigation efforts from three recent vehicle rulemakings at between $78 billion and $1.2 trillion (EDF, 2020). The current central estimate of the social cost of carbon is over $50 per ton in today's dollars. While this is the most robust and credible figure available, it does not yet include all the widely recognized and accepted scientific and economic impacts of climate change. For that reason, many experts agree this is far lower than the true costs of carbon pollution (EDF, 2020).

The social cost of carbon will therefore affect many countries in a variety of ways. This includes decision-making about investments in their future energy sector. Country leaders will have to consider the value of low carbon fuels and associated technologies. These costs are incurred in foreign currency (normally United States dollars). Therefore, Zambia may have to pay an increasing equivalent in Zambian Kwacha if the current annual inflation of 22.2% (BoZ, 2021) keeps rising.

2.4 Political Landscape

Politicians play a huge role in energy policies. A classic example is the former United States of America President, Donald Trump. During the campaign leading up to his victory in 2017, he stated that global warming was a hoax (Guarino, 2016). Considering the fact that he is now out of office, Joe Biden's new administration may now allocate resources towards 'cleaner' sources of energy which will greatly affect the country's future energy technologies.

Therefore, we need our politicians to seek advice from subject matter experts that have information which is backed by scientific studies with overwhelming evidence. Failure to convince our politicians on the best energy mix on feasible energy scenarios might mean little or no progress will be made towards securing a future without energy deficits.

2.5 Population

According to a 20-year period projection by Campbell (1997) from 1995 to 2025, a rise in population was projected to result in an increase in energy demand in England (Campbell, 1997). An increase in population means an increase in a country's basic needs whose factors of production are driven by access to electricity. Therefore, increasing population projections must serve as an indicator to invest in more energy sources that are efficient in addition to them being clean, constant, and scalable.

2.6 Cost of Energy Production Technologies

Energy technologies have different generation costs despite providing users with the same service. Commercial rooftop solar PV for example has a LCOE of about US$ 0.15/kWh but may only operate for 25 years (WattElectricalNews, 2016). Technologies such as nuclear are capital intensive, produce baseload electricity and may last for over 60 years (IRENA, 2014). Therefore, both long term reliability and profitability of different energy technologies may affect selection and adoption.

2.7 Energy Supply Sector Investments

Investments in energy supply are expected due to increasing energy demand with developed countries expected to make faster progress than developing countries (MacKay, 2009). As a result, predicting energy prices in developing countries is expected to become even more complex in the future. Following recent electricity tariff hike approval by ERB (PMRC, 2018), ZESCO expects a boost in energy sector investments as the new tariffs are favourably more attractive to investors than the old ones.

2.8 Transnational Terrorism

Trade conducted by terrorist groups such as Islamic State (IS) may have serious implications on future energy scenarios. According to Gordts (2014), IS was earning as much as US$3 million per day from trading unrefined crude oil with Turkey for weapons and cash (Gordts, 2014). This poses a potential risk of obtaining oil cheaply and selling it for higher prices. Since Zambia depends entirely on imports on crude oil and its by-products, transnational terrorism has a great influence on local fuel pump prices.

2.9 Energy Consumption Efficiency

Energy efficiency technologies have since experienced a number of '*rebound effects*' (Zach et al., 2012). This has prompted investments into renewable energy and storage technologies. Continuous improvements are expected over the years leading up to 2025 with Scotland's target of reaching 100% electricity generation from renewables by 2020 (Scottish-Government, 2016) as a good example. Even though Scotland failed to reach this target, it is left to be seen how this will affect energy technology adoption if it happens in the future.

According to Zach et al. (2012), various studies clearly showed that households opted to buy multiple appliances such as energy efficient bulbs as opposed to just what they required. Zambia might face similar challenges if residents decide to leave lights on simply because they are using cheaper energy efficient lighting.

Among the mentioned qualitative parameters, population, cost of energy production technologies, energy supply sector investments and energy consumption efficiency are reasonably quantifiable.

3. Case Studies

One particular case was the '*heat recovery from slag process in steel plants*' technology in the United Kingdom. The technology failed due to a lengthy payback period. According to Godet (2005), this technology would have been better placed to succeed had it been launched at a time when demand greatly exceeded supply (Godet, 2005). That way, the urgency in demand need supersedes the payback. It would have also likely received government funding.

Another similar case to analyse is the '*high efficiency heat pump using hydrogen absorbing alloy'* technology. This technology failed mainly because the organization did not expect hydrogen pipelines infrastructure to be in place by operation (Kimura, 2010). Godet and Roubelat (1996) suggest that organizations must take risks in making decisions (Godet and Roubelat, 1996). Had the organization taken this approach, it may not have doubted the technologies' competency. This implies that governments should also be willing to take risks in energy sector investments.

These studies concluded that in successful technology commercialization or failure, several factors are likely to enhance the chances of efficient energy technologies that emerge from public research and development. These are government support, clearly addressed market demand, deploying policies, and carrying out extensive evaluations of associated costs (Kimura, 2010).

4. Discussion

Energy scenarios that consider the mentioned parameters may be insufficient to ensure demand is always met. This implies that electricity imports, for example, will be required at some points throughout the year. However, the point at which the greatest imports will be required must not coincide with the predicted deficit period as the cost of imports may not be cost-effective.

Likewise, in an energy scenario where excess power is being generated, exports will be necessary to ensure that the grid is stable. If we are to introduce pumped-hydro storage (PHS) into the grid, such a scenario may still be insufficient to curtail excess energy produced. In the same manner, the energy storage capacity may not be sufficient to ensure demand is met by PHS. Therefore, an independent grid in a developing country without a good energy mix is impractical. Trade-offs must therefore occur between import and export choices.

Pumped-hydro storage (PHS) presents one suitable storage technology. When these stations have a double penstock arrangement, grid stability may be achieved. This is because double penstock PHS stations allow simultaneous generation and pumping for storage to occur at the same time (Gonzalez et al., 2012). This arrangement however almost doubles the costs of the PHS station (Connolly, 2013) and requires a large reservoir storage capacity to work effectively.

Using available pumped-hydro storage, problems that arise when supply fails to meet demand during low renewable energy generation periods maybe solved by the interconnections. It may also solve the problems that arise when supply fails to meet demand from available pumped-hydro storage during low renewable energy generation periods. To investigate the influence of interconnections on the developed scenarios, we may have to investigate the transmission capacity as well as the cost of transmission on foreign owned grid. This might be a lengthy consultation exercise, but existing power purchase agreements (PPAs) relations may provide such information prior to developing energy scenarios.

Zambia may benefit greatly from developing controlled biomass fields with trees being grown as biomass power plant feed stocks. The potential of biomass energy extraction and biomass to electricity in Zambia is untapped as shown by Zambia's Sankey diagram (IEA, 2018). Biomass power plants can produce baseload electricity and have a high-capacity factor but might be more expensive per MWh produced basis. Solar photovoltaic may be a good option because its resource is often available during peak periods of demand, that is, during the day. Therefore, it might be necessary to allocate a large share of solar photovoltaic due to the high radiation values and relatively smaller land footprint requirements.

5. Conclusion

Most energy scenarios have lots of uncertainty. Most hydropower stations for example, rely on past rainfall distributions making it difficult to plan precisely despite additional capacity buffers being put in place. If these figures are not critically analysed, the reliability of future energy scenarios may be greatly compromised. Furthermore, computational software may not assess the CO_2 emission footprint that comes from power plant construction machinery and transportation of required material such as concrete. Some energy scenarios are more accurate because they rely on solar radiation resource estimation for solar photovoltaic energy. This is because multiple reliable sources make data obtained fairly accurate. Solar radiation data also tends to be more reliable because the predicted resource can be verified during feasibility surveys on the site where a solar power plant will be constructed.

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Enhancing our Energy mix for the development of a resilient and sustainable Power Sector in Zambia

Andrew Munde[1]

Abstract

In the wake of the ravaging Covid19 pandemic which has not spared any Country world over, disrupting businesses in Commerce, slowing down the global economy, leaving the employment sector shrunk with massive job losses, inflicting health crises with majority of citizens in almost all nations paying the ultimate price of losing their lives, the need for a robust, resilient and sustainable Electrical power sector is inevitably more relevant now than ever before. A robust and resilient power system that meets the energy needs of any country without jeopardizing the future energy prospects of incoming generations world over cannot be overemphasized and Zambia is surely not an exception. However, the negating factor with respect to Zambia's Power Sector which has historically affected the country's electrical energy availability even before the era of the Covid19 pandemic, has been its mono-dependency on Hydropower Plants. These account for about 83% of the nation's electrical energy generation and the effects of Climate change resulting in partial droughts in recent years has drastically diminished the Power plants production capacity. The resultant was the national power deficit standing at 810MW at its peak between the years 2019 to 2020. In this vein, it is extremely imperative that the Energy mix in Zambia is enhanced to ensure the power sector becomes sustainable and meets the diverse energy needs of the Country's 18 million poeple. It is against the foregoing background that this paper was crafted to dissect the various options Zambia can implement to improve its energy availability that meets the needs of all its citizens and beyond to the Sub-Saharan Region. This paper therefore hinges on five key pillars that we need to exploit as a Country;

Keywords: Alternative, Energy, Mix, Resilient and Sustainable

1 Introduction

Zambia's electrical generating capacity from its national utility ZESCO's main and mini hydro power plants in addition to other Independent Power Producers or IPPs currently stands at about 2,897.21MW. This is broken down as 83% Hydro-based with the rest of the generation comprising coal (10%), HFO (4%), diesel (3%) and solar, less than 0.2 percent (ZDA, 2019).

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National access to electricity averages at 45% with 67% of the urban and 4% of the rural population having access to power (USAID 2018).

A flagship capital project utilizing the cascaded generation hydropower scheme dubbed Kafue Gorge Lower, is equally under development that is poised to inject 750MW (ZESCO, 2016) at its peak into the national grid once completed in the course of the year. It is expected to boost the nation's total installed capacity to about 3650MW when fully operational.

Notwithstanding these positive developments in the electrical power sector, the global negative effects of climate change have adversely affected the Country's available energy capacity with much of it dropping to about 1500MW in the country's drier season between September to November. This is a resultant of drop in water levels in the main reservoirs' dams at Kariba and Kafue Gorge Power Stations. Victoria falls power stations and the mini-hydro plants in the northern circuits such as Shiwang'andu, Lunzua, Lusiwasi and Musonda falls are equally not spared from such semi 'droughts'.

With national power demand standing at about 2300MW, the drop in generation leads to a deficit of about 800MW which inevitably calls for Load management through a deliberate Load Shedding program to save the power sector from total collapse.

With the recent advent of the Covid19 pandemic that the country is grappling with, such disruption of power affects the health sector negatively as sensitive medicines and vaccines cannot be chilled at lower temperatures as prescribed and some hospital machinery can not be run. Businesses too get affected in tourism, construction and social sectors among others.

The need to migrate from predominantly hydropower generation and enhance further, our generation mix through exploiting of other technologies such as Biomass plants becomes inevitable. To improve our energy mix further, the need to diversify our heating requirements such as use of Liquid Petroleum Gas for cooking and tapping the natural energy from the sun through use of Solar geysers are key.

As load demand is an ever-moving target and keeps increasing, it is also paramount to apply Demand Side Management (DSM) strategies to minimize power consumption while still adequately meeting our total energy needs.

The employment of Engineering Services Companies (ESCOs) for energy audits and optimization through Energy Savings Performance Contracts (ESPCs) have proved to be good DSM initiatives.

This study commenced with understanding the Policy framework that have overseen management of the Energy Sector both historically and in recent times including how it has shaped development of various initiatives towards power sustainability.

It proceeded to delve into the energy mix options available for exploitation in greater detail and singled out the main ones various stakeholders must consider moving towards a resilient and sustainable power sector.

2 Energy Policy-Institutional Framework

2.1 National Energy Policy

More than two decades ago, particularly in 1994, the Government of the Republic of Zambia through the Ministry of Energy promulgated the National Energy Policy (ZDA, 2019) to promote the following;

- Increase access to Electricity for the majority of Zambians
- Increase performance and efficiency of Electricity industry
- Attract private sector investments in development of potential generation sites
- The National Energy Policy was later revised in 2008 and 2019 to match modern-day energy sector developments

2.2 Energy Regulation Board, ERB

ERB was established in 1997 under the Energy Regulation Act of April 1995 and SI No. 6 of 1997 (ERB, 2017)

- Its main function was to regulate the Energy Sector in Zambia

2.3 Office for Promoting Private Power Investments, OPPPI

In 1999, OPPPI was established for:

- Project Identification
- Undertaking Feasibility Studies
- |Preparation of solicitation documents
- Implementation Strategy
- Procuring of developers
- Facilitating Implementation agreements

2.4 Rural Electrification Authority, REA

Rural Electrification Authority established in 2003 to manage the Rural Electrification Fund (REF) and increase Access to Electricity in rural areas from 3 to 51% by 2030.

2.5 Power Sector Development Master Plan, PSDMP

The Power System Development Master Plan was launched in February 2010 by the Minister of Energy at the time. Implementation timeframe was to run from 2010 to 2030

The Plan outlined least cost expansion options for Generation, Transmission and Distribution in Zambia

3 Development of Alternative Energy/Power Generation Schemes

As alluded to in the preamble, overdependence on hydropower plants to meet the nation's energy needs has been eroded in the past owing to effects of climate change and reduced rainfall in many seasons. The reduction in rainfall activity amounts to drop in water levels and thus diminishing generation from the hydropower plants.

One technology that this study analyzed and that is proposed for development is the use of waste to generate electricity.

3.1 Waste-run Electric Power Plants

In many of Zambia's urban towns, it is not uncommon to find heaps of waste or garbage that many municipalities grapple to deal with. Part of the waste also include Biomass from woodchips and huge heaps of saw dust from sawmillers.

The study therefore proposed that in each geographical zone, such as a town or province, all this waste can be transported to one designated place where there is ready access to water.

The waste would then be burnt as primary fuel to generate steam in the boilers that would inturn drive the steam turbines for power generation. These power plants would then be synchronized to the grid through a nearby Distribution or Transmission system in a *distributed generation scheme (en.wikipedia, 2020).*

3.2 Co-generation of Heat and Power (CHP)-District Heating Technology

Part of the power produced from Waste-run power plants would further be utilized to run water pumps that drive the condensed steam or hot water through a series of pipes laid and connected across the town to individual buildings and households for cooking or heating purposes.

After usage, the water is made to go through chillers for cold water usage.

This CHP Closed loop technology eliminates the need for Heaters, Electric geysers and air-conditioning units drastically reducing the need for electric power energy owing to a centralized heating and cooling system. Temperature regulation is achieved by means of a thermostat at individual premises. The chart below gives a graphical outline of this technology

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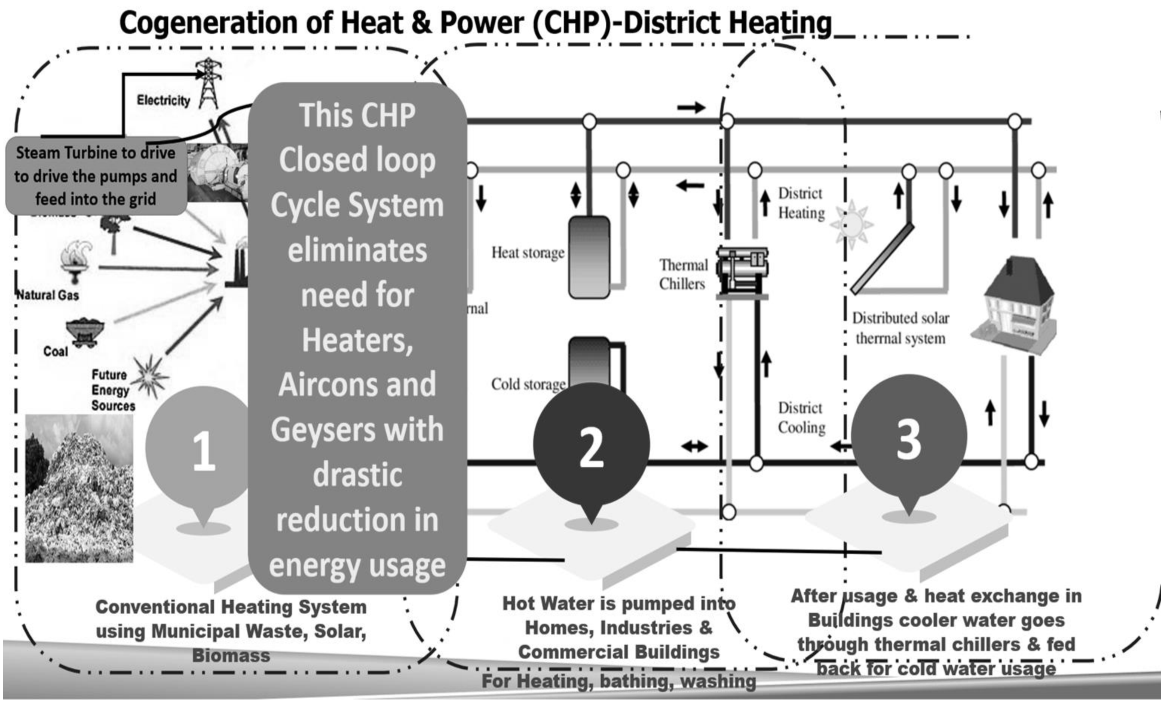


Fig 2: Pictorial outline of the CHP Scheme for District Heating

3.3 Use of Liquified Petroleum Gas (LPG) for Heating

The study proposed the adoption and massive role out in the use of LPG for Heating and Cooking needs in both homes and Commercial entities. This has proved to be a good substitute for electricity and leads to much less burden on the electric power grid. A study was done on how the use of LPG would impact Zambia’s national grid if used by all clients.

This is illustrated in the chart demonstration in Figure 3.

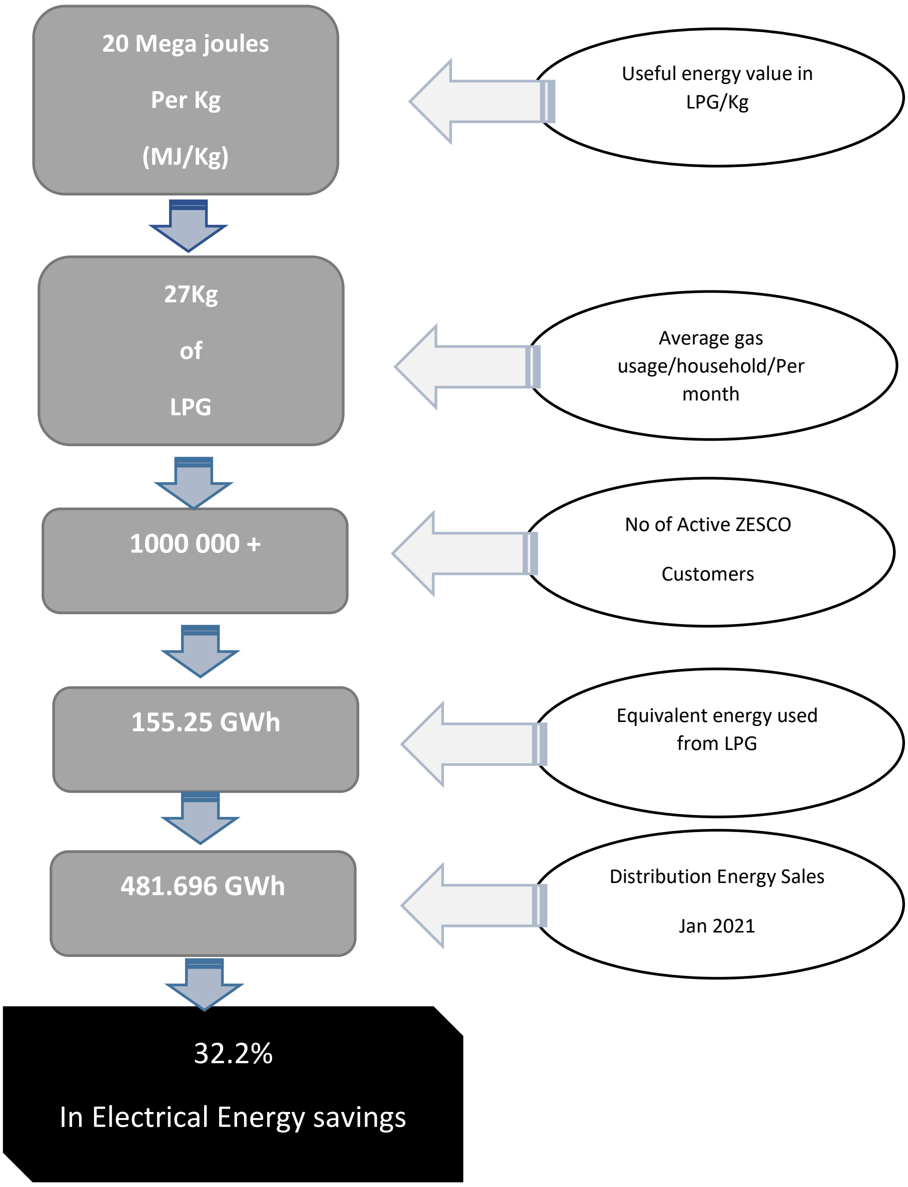
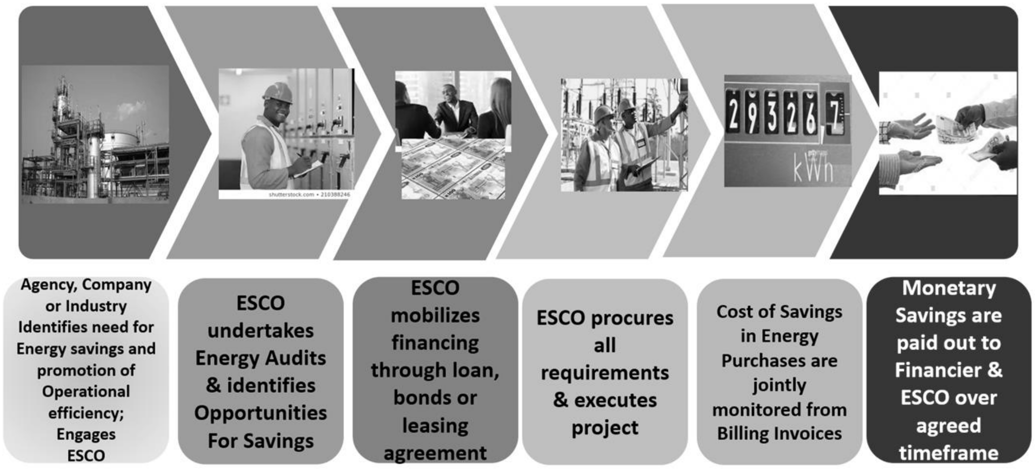


Fig 3: Energy Use through LPG

The figure shows that if all One Million plus Customers with ZESCO migrated to using LPG for heating and cooking, that would translate to 32.2% of electrical energy savings on the Distribution network thus relieving pressure off the grid and freeing up that energy for other need areas.

4 DSM initiative-Energy Savings through performance Contracts

A study was further conducted on Demand Side Management initiatives that would help in attaining a sustainable power sector, and Energy Savings through Performance-based Contracts (ESPC) was one such finding. The scheme of how ESPCs work is showcased below (ESPC,



2021);

Fig 4: ESPC outline

4.1 ESPC Outcomes

- No upfront Project costs on the client
- Reduced Plant Energy usage and Billing
- ESCO earns markup on project costs over time through savings on energy bills
- Financier recoups principal plus interest
- Utility applies saved energy for network expansion

5 Discussion

While Hydro Electric power generation is clean, cheaper to run and can easily be transmitted, the study showed that its vulnerabilities to negative climatic conditions easily affects the plant generation capacity thus diminishing supply of the much-needed energy in the country.

In the current wake of the Covid19 pandemic, the need for a resilient and sustainable energy sector is non-negotiable and key to the nation’s survival.

This study, after analyzing various available scenarios and technologies that could help us go through this patch with minimal impact, established that enhancing our energy mix is key if we are to achieve a resilient and sustainable power sector. Distributed generation schemes through use of waste as fuel to generate electricity was one such technology that would be easy to implement to aid in attaining energy sufficiency. Co-Heat and Power generation if incorporated with District heating networks, can significantly reduce the burden on the grid through elimination of heating needs in homes using electricity.

The use of LPG for heating and cooking is equally one the study strongly recommended in that more than 30% of energy used by ZESCO's Distribution clients can be saved if adopted by all.

As loads are constantly growing, the need to use energy efficiently was also studied. It was proposed from the study that firms could adopt the use of Energy Savings Performance Contracts as one such tool of Demand Side Management initiatives.

6 Conclusion

From the study undertaken, it was apparent that the overdependence on Hydro Electric Power schemes as the major form of electrical energy generation in Zambia is unsustainable due to the inevitable effects of climate change which has diminished the Country's available power thus negatively affecting virtually all sectors of the economy. The emergence of Covid19 pandemic has further exacerbated the situation.

Notwithstanding, exploring and implementing available technologies that promote a resilient energy mix coupled with well-thought through Demand Side Management initiatives will ultimately revitalize the Country's Energy Sector. The various undertakings through Solar-Scaling projects, ZESCO's energy efficiency programs, and the current growing demand for LPG to meet the citizens heating needs are instances of evolving Energy Sector surely headed in the right direction of sustainability.

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Sustainability and fate of small-scale gold mining operations in Africa in COVID-19 time of disruption: A socio-economic resilient consideration

Nirdesh Singh[1] and Antoine Floribert Mulaba-Bafubiandi[1]

Abstract

Small-scale gold mining is usually "poverty driven" in countries within Africa. Certain countries in Africa have an abundance of unexploited mineral wealth. The concept of sustainability in mining is holistic and considers economics, society, and environmental constraints in its measurement. The negative connotations associated with small-scale mining poses a threat to its long-term sustainability. Coupled with this are the disruptions (social, political, health, safety, environmental, climatic, technological) that are continuously faced by the sector of which the COVID-19 pandemic has had a devasting impact. This paper conducts a review of literature and does an analysis of the impact of the disruptive pandemic of COVID-19 on small-scale mining operations in Africa. To remain sustainable these operations have to be more resilient than ever. It proposes a way in which the sector can overcome disruptions to reach sustainability and positively contribute to the global Sustainable Development Goals (SDG's).

Keywords: COVID1-19, disruption, small-scale, mining, sustainability

1. Introduction

1.1 What is small-scale mining?

The terms artisanal mining and small-scale mining are often lumped and tend to cause confusion. These are normally associated with mining and processing activities undertaken by groups of people, families, or small businesses in developing countries across the world. It is usually a means of livelihood and provides jobs for millions of people in Africa, where it is the most important income generating activity after farming (Geenen, *et al*., 2020). Mining at artisanal and small-scale is usually "poverty driven" in rural areas of countries with an abundance of unexploited mineral wealth. Miners are nomadic and can easily move from one mining site to another in search of more financially viable opportunities (Aizawa, 2016). To the miners the economic benefit outweighs the risks taken and the threats posed within the sector.

The distinguishing factors between "artisanal" and "small" include but are not limited to production volume, annual sales, number of people employed, capital invested, size and quality

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of the mineral reserve and the level of mechanisation used (Hentschel, *et al*., 2003).

In South Africa, small-scale mining is defined based on the National Small Business Development Act of 2003.

Table 1:The classification of mining in South Africa based on the National Small Business Development Act (Government Gazette, 2003)

Size or class	**Total full-time equivalent of paid employees - Less than:**	**Total annual turnover - Less than: (ZAR million)**	**Total gross asset value (fixed property excluded) - Less than: (ZAR million)**
Medium	200	30,00	18,00
Small	50	7,50	4,50
Very small	20	3,00	1,80
Micro	5	0,15	0,10

This system shown in Table 1 classifies mining operations into the categories of micro, very small, small, and medium businesses. It uses the criteria of number of paid employees, annual turnover, and gross asset value to distinguish between categories. Some believe that artisanal operations are a sub-set of small-scale mining which from Table 1 consists of micro, very small and small businesses. It is a continuum where artisanal operations grow to become small-scale operators (Debrah, *et al.*, 2014).

1.2 The sustainability of the sector and the threat of disruptions

According to Aizawa (2016) economic benefit is a combination of the miner's "perception" of income, income stability and their career aspirations. Social benefit on the other hand in practice is associated with dependence on family, friends, and other workers. Both are important in the pursuit of sustainability and one cannot outweigh the other.

From an analysis of mineral data obtained from Fritz (2018), gold was found to be the most widely mined and processed commodity by artisanal and small-scale miners in Africa. The sustainability of these gold mining operations has, however, been a topic of debate for many decades. Sustainability of mining operations (Seccatore, et al., 2015) in general need to consider the overlap of the following aspects:

1. Economic growth;
2. Society (in conjunction with socio-economic development); and
3. Health, Safety & Environmental management.

The concept of sustainability is holistic. The three aspects are interactive and should be "simultaneously" and not "sequentially" applied (Asr, *et al*., 2019). Seccatore (2015) affirm that "Small-scale mining operations will only be sustainable when it comes out of the artisanal dimension and can only be defined by the limits of its productivity." In theory a perceived advantage of small-scale mining that assist in making it sustainable is the quicker installations (set-up) of mining equipment/operations, lower technological/capital costs and quicker short-term payback which makes it easier to respond to variations in market demand (Seccatore, *et al*., 2015).

This theory is, however, tested in practice especially when there are disruptions experienced in small-scale mining operations. Some of these disruptions are known by the miners, are expected during the mining-life cycle, are dependent on society, the mining process, market conditions and country specific mining & environmental regulations. These disruptions include conflicting interest, communicable diseases like HIV and Ebola, aggressive female and child labour, school dropouts, alcoholism, prostitution, truancy, teenage pregnancy, social disruptions, and injuries (Bansah 2018, Meaza 2015). There are also environmental, geographical, and climatic conditions that need to be considered like the availability of fresh water for processing needs. Drought and water shortages affect the productivity, hence in Ethiopia for example the months of May to August is the peak for small-scale gold mining operations and is an essential source of income for "landless farmers" (Meaza, *et al*., 2015).

COVID-19 and the novel coronavirus has, however, been a disruption that was unexpected and at the time of writing this paper has lasted in many countries for almost a year. The end of this pandemic is not in sight with second waves being experienced and third waves predicted if vaccines are not procured and rolled out timeously. This has impacted the small-scale mining sector significantly especially in Africa even though the rate of infections has not been as large as in countries within Europe and Asia (Grace, 2020).

This paper conducts a review of literature and does an analysis of the impact of the disruptive COVID-19 pandemic on small-scale mining operations in Africa and how this will affect the sustainability of this essential job-creating livelihood for millions of people going forward. To remain sustainable these operations have to be more resilient than ever. It proposes a way in which the sector can overcome disruptions to reach sustainability and positively contribute to the global Sustainable Development Goals (SDG's).

2. The impact of disruptions on small-scale mining caused by COVID-19

2.1 Disruptions

The novel coronavirus of 2019 spread globally and has had devasting effects, some of which will be long lasting. Countries had to take drastic measures to control and reduce the spread of the COVID-19 virus and this resulted in lockdowns which in many cases meant the closure of international borders, businesses, social services, and schools. The consequence of this being setbacks across the economies of African countries. Due to Africa's perceived lower resilience and diversification, the economic impact will be much greater as compared to Europe and Asia. It is predicted that Africa's GDP will drop by 1.4% due to the impact of COVID-19. If the world were to experience a "deep recession" there will be "a further drop in Africa's total exports by 16.7% with the resultant revenue losses of up to 5.3%". Exports of minerals, ores and metals could then see a decline of up to 10% (Grace, 2020).

The artisanal and small-scale mining sector has always been a significant contributor to the metals/mining sector within African countries even though the sector is plagued with challenges and uncertainties. It has created livelihoods and jobs for several unemployed people mostly within rural communities. With COVID-19 now a global pandemic this will further put a strain on this sector and the families that are dependent on this to earn a living. A study conducted by Geenen (2020) found that the estimated pay of the small-scale gold miners in the DRC categorised according to the type of work done is as follows: pit managers (USD191 per week), right hands (USD92 per week), experts (USD52 per week) and other mining functions (USD24 per week).

According to the recent research done by Hilson (2020b) it was stated: "In sub-Saharan Africa, few industries stand to be impacted more by the global COVID-19 pandemic than artisanal and small-scale mining". There are an estimated 8.2 million workers directly involved and 44.9 million dependents (indirectly involved) in artisanal and small-scale mining across Africa. Downstream the impact will be felt on equipment suppliers, distributors of mercury (used to amalgamate gold), onsite vendors that include, food suppliers through to sellers of various items of clothing and fuel, and accommodation services. The artisanal and small-scale mining network is "multi-layered" and goes deep into the supply chains. A large proportion of this network is, however, informal which implies that they are most susceptible to these shocks, stresses and disruptions caused by COVID-19. The impact of this pandemic on rural communities and poor households within sub-Saharan Africa needs to be better understood (Hilson, 2020b). This will surely be a topic of research for many, that will continue for years to come.

2.2 The impact and effect of COVID-19

The impact of COVID-19 on the small-scale gold mining sector of Mali, Liberia and Ghana was researched by Hilson (2020b). In each case, interviews were conducted with 15 miners in each country either through in-person interviews (social distancing observed) or WhatsApp calls. A questionnaire was developed and covered six major themes i.e., gender, health and safety, food security, security, services, and supply chains. The findings of this research were analysed and is summarised in Table 2 showing the effects of COVID-19 on the gold miners and the communities.

Table 2: Summary and Analysis of the impact of COVID19 on small-scale gold miners in Mali, Liberia, and Ghana – based on research conducted by Hilson (2020b)

Country	Summary of Findings, Impact and Challenges of COVID-19	Effects
Mali	All miners interviewed were women. Women constitute more than 50% of the sectors workforce. Restrictions imposed by government to stop the spread of the pandemic, especially the lockdown of borders meant that people were unable to travel impacted the income generation opportunities for women. There was an increased in police presence. Women interviewed (all in possession of gold washers' cards) had abided to law and ensured that they continuously sanitised, wore masks and social distanced. There was a perception that the price of gold had dropped and the curfew times of 9pm to 5am (8 hours) resulted in fewer buyers onsite. The time used for gold production also reduced due to curfew. The cost of food had escalated and the reduction in household income resulted in financial distress. Some miners have resorted to seeking loans from friends. Closure of schools meant that children stayed at home and women were required to care for them and this impacted their ability to work.	Reduced working hours (production). Reduced commodity (gold) prices. Reduced Income Generation – financial distress. Required loans to support families.

Liberia	All miners interviewed were in possession of mining licenses (Class C) and all complied with the government COVID19 rules and regulations. Mining and processing sites had "hand-washing" buckets in place and adherence to social distancing, but this resulted in a reduction of daily manpower to avoid overcrowding. Originally curfew times were 3pm - 6am (15 hours) but were then amended to 6pm - 6am (12 hours). Buyers of gold had stayed away from mining sites. Those that previously bought gold have saved them (investors and brokers). The lockdown restrictions resulted in a reduction of supply and delivery of food and other commodities into the country. The prices of rice and fuel hence increased.	Reduced manpower. Reduced buying of commodities (gold). Food supply shortage. Increase in price of food and fuel.
Ghana	The original 21-day country lockdown resulted in a decrease in the price of gold. The supply chains are extremely fragile and slight disruptions have a huge impact that cascades through the chain. The effect was that families battled to buy food and essential items due to reduced earnings. Even though production continued, the number of buyers were reduced due to restrictions imposed by government. Certain businesses could not continue as cost of tools/consumables required for production increased.	Reduced commodity (gold) prices. Reduced buying of commodities (gold). Increase in prices of tools and consumables needed for production. Reduced Income Generation – financial distress.

3. How do small-scale mining operations become more sustainable and resilient to disruptions?

3.1 Proposed process to mitigate disruptions and move to sustainability

The proposed process to achieve sustainability is shown in Figure 1. It takes into consideration the effects of the disruptions experienced by the sector and combines many of the suggestions made in literature over the years. The sub-components are discussed in the sections to follow.

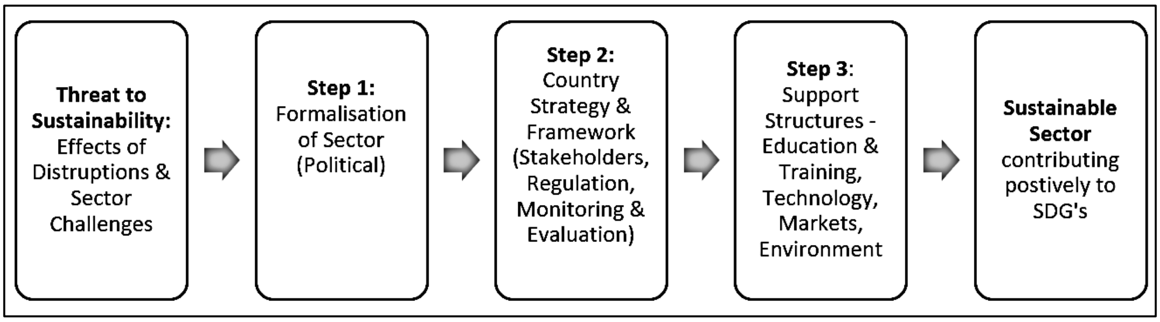

Figure 1: Proposed steps to achieving sustainability in the small-scale gold mining sector

3.1.1 Education and Training

Part of building resilience is improved and ongoing education and training (Asr, *et al.*, 2019) of small-scale miners, mining communities and the deep downstream supply network. Part of this strategy to increase awareness and make provision for training, needs to be incorporated into the country specific mining legislation and policies. Stakeholders within the sector need to work together to address issues that threaten the sustainability of small-scale gold operations (Meaza, *et al*., 2015). These stakeholders include government ministries/departments (political influence), private sector, development partners, funders, social scientists, and technical specialists.

3.1.2 Mining and Processing Technology

Technological improvements within the sector have made some of the operations more productive even though the downside to this was a reduction in labour. These continuous improvements are required to help build resilience in production capacity even when manpower is low especially during times of a pandemic like COVID-19. According to Bansah (2018), in Ghana there is now more use of excavators, bulldozers, drilling equipment, and semi-mechanized washing plants across small-scale operations. The size of the operations is increasing which is an indication that they are generating more revenue and moving towards sustainability.

3.1.3 Sustainable Development Goals (SDG's)

The plans of large-scale mining operations which are generally prioritised by government in developing countries (Hilson, 2020a) are linked to the global Sustainable Development Goals (SDG's). Small-scale mining should be no different and these activities needs to be linked to the SDG's to ensure sustainability. These integrate social and economic development with environmental objects hence increasing the scope for sustainable development (Hirons, 2020). The research done by Hirons (2020) identified at least 11 of a possible 17 SDG's that small-scale mining could be linked to while Hilson and Maconachie (2019) had identified 8 SDG's. The combination of these SDG's is shown in Figure 2 2 and the result is that a contribution to 14 SDG's can be made by the small-scale mining sector.

Figure 2: The 14 SDG's that small-scale mining can contribute and be linked to.

The challenge, however, with this linkage and providing a "positive" contribution to the SDG's is the informality of several of the small-scale gold mining operations, lack of information or measurable operational data and the complex social dynamics around these communities. The danger is that the effect could be a negative one and result in the sector being undermined (Hirons, 2020), if proper support strategies are not put in place. This will require a "change in the mindset" of both governments and people in general towards small-scale mining. Governments will need to affirm their commitment to the sector and a thorough knowledge of the ins and outs of this industry is required. Currently the sector has not been mapped to the SDG's and only large mining operations are seen to contribute (Hilson & Maconachie, 2019).

3.1.4 Formalising the sector

For the linkages to the SDG's to succeed the sector in Africa needs to be formalised. According to Bansah (2018) formalising the sector will involve several steps. These include

1) educating all stakeholders and obtaining commitment;
2) regulating all mining activities with appropriate policies and laws;
3) having structures and systems in place for control and monitoring purposes; and
4) including special taxes to generate revenue to develop and sustain the small-scale mining sector and affected communities.

In Senegal, the government systems that were put in place were able to successfully deal with any conflict and disputes amongst the small-scale mining community. The policies and regulation provide the required technical assistance, has provision for special taxes which is then used to support the development of the community. There is a need for other governments that wish to follow the same path to apply an approach that is "sensitive to local context" and expands on existing "customary governance structures" when developing the policies and regulations for the small-scale mining sector (Huntington & Marple-Cantrell, 2021).

To assist in formalising the sector some governments have opted to reduce the legal risks faced by small-scale miners by making provision of "demarcated areas" that can only be used for exploration and further mining/processing. This then motivates the miners to legalise and apply for the appropriate licenses required hence qualifying for royalties and other tax incentives. Government is, however, encouraged to provide further support and safety nets for social protection in areas where mineral deposits/resources are low and extraction/production costs could potentially be very high (Aizawa, 2016).

4. Conclusion

The small-scale mining sector has been in existence before the inception of the large-scale mining industry but has not fully be acknowledged or recognised as a contributor to the economy of many developing countries. Instead, it is looked upon by many negative connotations due to its societal challenges and this paints a bleak and unsustainable future. The sector has over the decades made some inroads but like everything else it is susceptible to disruptions. It is evident that the COVID-19 pandemic has severely impacted the small-scale gold mining operations in Africa. The price of gold has reduced, production costs have increased, miners are unable to work sufficient hours in a day to help improve productivity due to the pandemic restrictions. This has resulted in financial distress and has severely impacted supply chains which are also an integral part of the sector.

The sector needs to become more resilient to achieve sustainability. Formalising the sector is the first step. Country specific policies and regulations need to be put in place. A strategy and framework need to be developed together with relevant stakeholders to be able to monitor and evaluate progress made. Incentives need to be offered to motivate gold miners to legalise and formalise their businesses. The sector if correctly structured and supported can contribute positively to 14 of the 17 global SDG's.

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Precipitation of Copper and Cobalt from Metallurgical Process Solutions

Rodrick Lamya[1], Malimba Masheke[1] and Leonard Kabondo[1]

Abstract

The precipitation behaviour of copper and cobalt from metallurgical process solutions was studied by the precipitation process to establish the feasibility of recovering copper and cobalt from the solutions. Thus precipitation tests were carried out to investigate the effect of pH and precipitating reagent type on copper and cobalt precipitation. The results of tests conducted to investigate the effect of pH showed that most of the copper precipitated out at pH 5.5 – 6.0, but the degree of precipitation was even much more for tests conducted at a higher pH of 8.0 – 8.50. It was noted that over 95% of Cu precipitated within 30 minutes while over 70 % of Co precipitated within the same period when lime was used as the precipitating reagent.

Results of the tests conducted to investigate the effect of type of precipitating reagent on Cu and Co precipitation showed that lime was generally more effective than NaOH, Cu precipitated less with NaOH, while the degree and rate of Co precipitation were lower for NaOH. However, it should be noted that at a pH of 5.5 – 6.0 Co precipitation is low as cobalt precipitates at a higher pH than Copper. Furthermore it was observed that the rates of Cu and Co precipitation were high with over 95% of Cu being precipitated within 30 minutes and over 70 % of Co precipitated within the same period when lime was used as the precipitating reagent.

The present study has shown that copper and cobalt can be recovered from metallurgical process solutions via the precipitation process using lime as the precipitating reagent at a pH value above 6 and a residence time of less than 4 hours. Sodium hydroxide proved to be less effective as a precipitating reagent for copper and cobalt under the conditions applied in the present study.

Keywords: Solution, Precipitation, Copper, Lime, Sodium hydroxide

1.0 Introduction

Precipitation is the formation from solution of a solid product as the result of change in concentration of solution or addition of a reagent to the solution. Metal precipitation occurs when the concentration of metal ions in the solution exceeds the solubility product of the precipitate

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(Wang, *et al*., 2005), and can be induced by changes in the ionic equilibrium of the system with the addition of a suitable reagent. Precipitation processes can be used both as a means of separation of a metal or group of metals from others and as a means of recovery of metals from solution. It can also be employed for the purpose of removing impurities or minor metallic constituents from solution. After precipitation, the precipitate is separated from the solution by thickening and/or filtration.

Precipitation of metals from aqueous solutions of metallurgical process solutions and other metal bearing solutions such as industrial wastewaters and acid mine drainage (AMD) can be achieved by the formation of their respective hydroxide or sulphides or carbonate salts (Pang, *et al*., 2009; Brbooti, *et al*., 2011; Blais, *et al*., 2008; Arbabi and Golshani, 2016; Zhang and Duan, 2020), depending on the type of precipitating reagent used. The selective precipitation of metal hydroxides by controlled changes of pH is perhaps one of the best known and most widely used method for the removal of certain metals from impure leach liquors (Monhemius, 1977). Recovery efficiencies of the metals by precipitation is highly dependent on a number of factors including the following: metal concentrations in the solution, pH of the system, the presence of a complexing ion and the presence of an oxidizing or reducing agent (Abdullah, *et al*., 1999; Lin, X. *et al*., 2005). Precipitation of metals consists of three major stages namely nucleation, growth of nucleus and aggregation or crystallization (Benning & Waychunas, 2007). In most precipitation processes certain chemicals known as precipitating agents or precipitant are added to induce the precipitation and subsequent crystal formation (Wang, *et al*., 2005). Lime (CaO) and sodium hydroxide (NaOH) are the most commonly used precipitants where the method of metal precipitation involves adjusting pH of the solution by neutralization of acidic solutions, resulting in the precipitation of metal hydroxides. The principle of neutralization using lime relies in the insolubility of metals in alkaline conditions. By controlling pH to a certain value, metals such as Cu, Mn, Fe and Zn can easily be precipitated at a relatively low pH values, whereas other metals such as Co, Ni and Cd require higher pH values to effectively precipitate their hydroxides. Other precipitants such as Sodium metabisulpide and NaHS can be used but in this case metal precipitation is caused by lowering chemical potential of the solution system.

In some precipitation processes carbonate compounds are used to precipitate metals as metal carbonates, in which straight precipitation by chemicals such as calcium carbonate is used or the conversion of hydroxides to carbonates is applied for the precipitation of metals (Wang, *et al*., 2005). Carbonate precipitation can also be applied in combination with hydroxide precipitation. The advantage is that it can be used at low pH, with faster precipitate settling and good metal recoveries. (Turan, *et al*., 2004).

This study was conducted to investigate the precipitation behaviour of copper and cobalt from mine tailings leach effluent solution with a view of ascertaining the feasibility of recovering copper and cobalt from the solutions.

2.0 Experimental

2.1 Material and Experimental procedure

The solution used in this study was a tailings leach effluent solution with 620 ppm copper and

140 ppm cobalt. A bulk solution sample of about 20 litres was collected from a metallurgical processing plant and stored in a plastic container and this solution was used for all the tests conducted. The precipitation tests were performed in a mechanically stirred five litre plastic vessel provided with a cover and fitted with an overhead stirrer and a pH electrode. All the tests were conducted at constant stirring speed (400 rpm) and at ambient temperature with the temperature of the precipitation system being monitored by taking measurements at predetermined time intervals of about 20 minutes.

In this study the method of metal precipitation entailed adjusting pH of the reaction mixture by neutralization of the acidic metallurgical processing plant solution, resulting in the precipitation of metal hydroxides. Thus tests were carried out to establish the effect of pH and type of precipitating reagent. In the tests conducted to determine the effect of pH on copper and cobalt precipitation, the pH of the reaction mixture was maintained within two pH ranges namely 5.5-6.0 and 8.0 - 8.5. For tests conducted to determine the effect of type of precipitant on copper and cobalt precipitation lime and sodium hydroxide were employed. The initial solution volume was maintained at 2 litres in all the tests, and copper and cobalt concentrations of the solution were determined before commencement of each test. The parameters which were investigated and their values are presented in Table 1.

Table 1: Experimental Precipitation Conditions

Parameter	Values Investigated
Type of Precipitant	Lime and NaOH
Reaction mixture pH	5.5 – 6.0 and 8.5 – 8.0
Temperature (^{o}C)	Ambient

A typical experimental procedure was as follows: Two litres of the sample solution was added to the precipitation reactor, pH of the initial solution was measured using a Jenway 3510 pH meter prior to commencement of the test. The stirrer was fitted with a flat blade turbine type impeller and set at a constant speed of 400 rpm. The pH of the reaction mixture was maintained at the desired value by the addition of quick lime or NaOH, while concentrated sulphuric acid was used to drop the pH when it was higher than the desired value.

At a predetermined time interval of one hour samples were taken, except for the first sample which was taken after 30 minutes, and immediately filtered. All the solution samples were analysed for copper and cobalt using PinAAcle 500 PerKin Elmer Atomic Absorption Spectrophotometer (AAS); where it was necessary, solid samples were dried before being analysed using an FEI, FEG450 Scanning Electron Microscope (SEM). All samples were analysed in the Metallurgical laboratory of the Copperbelt University.

3.0 Results and Discussion

3.1 Effect of pH on Copper and Cobalt Precipitation

Results of the precipitation tests conducted to investigate the effect of pH on Cu and Co precipitation are summarised in Table 2, which shows Cu and Co concentrations of final test solutions and final Cu and Co percent precipitation. Table 3 shows *c*opper and cobalt metal concentrations during the precipitation process at pH values of 5.5 – 6.0 and 8.0 – 8.5; while Figures 1 and 2 present both metal concentrations and recoveries. It should be mentioned that the graphs of metal concentrations tend to superimpose on each other due to the low concentrations in the solutions. It should also be noted that average values of test results were used in all the Figures. All the tests were conducted at ambient temperature, lime was employed as the precipitant and the residence time was 4 hours.

Table 2: Results of tests conducted to determine effect of pH on copper and cobalt precipitation

pH		Cu conc.(ppm)		Cu Preciptn. (%)	Co conc. (ppm)		Co Preciptn. (%)
Initial pH	**Test pH**	**Test conc.**	**Avg conc.**		**Test conc.**	**Avg conc.**	
1.74	5.5 – 6.0	1.50	0.95	99.80	10.70	10.80	82.42
1.72	5.5 – 6.0	0.40		99.91	10.90		82.00
1.63	8.0 – 8.5	0.71	0.46	99.96	2.50	2.10	99.25
1.76	8.0 – 8.5	0.20		99.92	1.70		97.38

Precipitation conditions: Feed Solution: 620 ppm Cu, 140ppm Co, Ambient temperature, Precipitating reagent: lime, Residence time: 4 hours

The results show that for tests conducted at pH 5.5 – 6.0 most of the copper precipitated out but the degree of precipitation was even much more for tests conducted at a higher pH of 8.0 – 8.50. At the pH of 5.5 – 6.0 the amount of copper remaining in the solution after the test was an average of 0.95 ppm while for pH 8 – 8.5 it was 0.46 ppm. Copper concentration in the feed solution was 620 ppm, thus an average 99.85% Cu and 99.94% Cu were precipitated at pH 5.5 – 6 and pH 8 – 8.5, respectively. Average cobalt concentrations of solutions after 4 hours were 10.80 ppm at pH 5.5 – 6 and 2.10 ppm at pH 8 – 8.5. The feed concentration was 140 ppm Co, thus an average 82.21% Co and 98.32% Co precipitated out at pH 5.5 – 6.0 and pH 8.0 - 8.5 respectively.

Table 3: Copper and cobalt metal concentrations at pH values of 5.5 – 6.0 and 8.0 – 8.

Residence time (hrs)	pH 5.5 – 6.0 Metal conc. (ppm)		pH 8.0 – 8.5 Metal conc. (ppm)	
	Cu	Co	Cu	Co
0	620.00	140.00	620.00	140.00
0.5	4.00	14.65	1.16	13.40
1	2.80	14.20	1.06	8.23
2	1.90	13.40	0.64	2.75
3	1.65	12.30	0.61	2.29
4	0.95	10.80	0.46	2.10

Precipitation conditions: Feed Solution: 620 ppm Cu, 140ppm Co, Ambient temperature, Precipitating reagent: lime,

Figures 1 and 2 show precipitation kinetics of Cu and Co at pH 5.5 – 6.0 and pH 8.0 – 8.5, respectively. Figure 1 shows residual Cu and Co metal concentrations of the solution versus residence time as well as percent Cu and Co precipitation as a function of residence time at pH 5.5 – 6.0; while Figure 2 shows Cu and Co concentrations of the solution as well as percent Cu and Co precipitation as a function of residence time at the pH 8.0 – 8.5.

It can be seen that in all the tests conducted copper and cobalt precipitation was high at both pH values, although results for pH 8 – 8.5 were slightly better. For tests conducted at pH 5.5 – 6.0 the concentration of Cu in solution decreased from 620 ppm to an average of 0.95 ppm after 4 hrs (Table 3 and Figure 1), while at pH 8.0 - 8.5 it decreased from 620 ppm to an average of 0.46 ppm (Table 3 and Figure 2). On the other hand, Co concentration decreased from 140 ppm to an average of 10.80 ppm at pH 5.5 - 6.0 (Table 3 and Figure 1). At pH 8.0 - 8.5, the concentration decreased from 140 ppm to an average of 2.10 ppm (Table 3 and Figure 2). It can be seen that both the degree and rate of Cu and Co precipitation were marginally higher at the pH of 8 – 8.5 (Table 3 and Figures 1 and 2). It should be noted that over 95% of Cu precipitated within 30 minutes and over 70 % of Co precipitated within the same period at both pH values of 5.5 - 6.0 and 8 – 8.5 when lime was used as the precipitant (Figures 1 and 2).

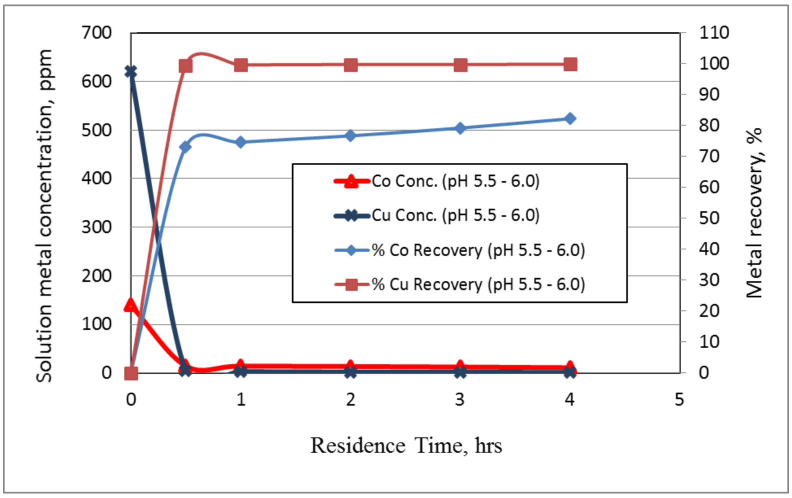

Figure 1: Kinetics of Cu precipitation at pH 5.5 – 6 (Ambient temperature, precipitating reagent: lime)

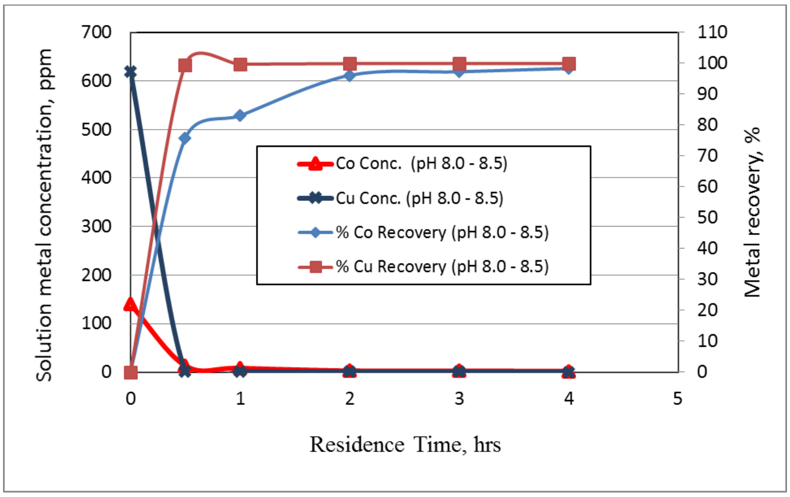

Figure 2: Kinetics of Co precipitation at pH 8.0 – 8.5 (Ambient temperature, precipitating reagent: lime)

The Cu and Co precipitation were effected by the addition of lime to neutralize the acidic solution and thereby increasing the pH to the values where formation of copper and cobalt hydroxides took place. As soon as solubility products of copper and cobalt hydroxides were exceeded the hydroxides precipitated out of the solution. The principle of using alkaline reagents such as lime to precipitate metals relies in the insolubility of metals in alkaline conditions; hence by adjusting pH of the solution to a certain value, metals can easily be precipitated. The solubility of different metals in aqueous solution vary, for example copper II ions (Cu^{2+}) start to precipitate at a lower pH value than that of cobalt ions. Each metal in solution has a pH value at which optimum hydroxide precipitation takes place. Abdullah and co-workers (1999) explained the mechanism of heavy metal hydroxide precipitation in terms of coagulation of colloidal particles. It is believed that Ca^{2+} ions from lime act as charged counter-ion to the negatively charged colloid. As a result, negatively charged colloid will be destabilized by the Ca^{2+} ions and this allows coagulation of colloidal particles of metals and formation of the hydroxide precipitate at high pH values. Secondly, the co-precipitation role of ferric hydroxide, if present, during hydroxide precipitation can also be taken into account to explain why no re-stabilization of dissolved metal species occurs at high pH.

The generalized equation for the metal hydroxide precipitation can be written as:

$$M^{2+} + 2(OH)^{-} \rightarrow M(OH)_2 \qquad [1]$$

where M is a divalent metal ion, OH is an hydroxide ion emanating from the precipitant and M(OH) is the metal hydroxide.

The precipitation of copper by lime takes place according to reaction [2], while cobalt precipitation occurs according to reaction [3].

$$CuSO_4\ (aq) + CaO\ (s) + H_2O\ (l) \rightarrow Cu(OH)_2\ (s) + CaSO_4\ (s) \qquad [2]$$

$$CoSO4\ (aq) + CaO\ (s) + H_2O\ (l) \rightarrow Co(OH)_2\ (s) + CaSO_4\ (s) \qquad [3]$$

From the reactions above, it is can be seen that both copper and cobalt precipitate as hydroxides and calcium sulphate, thus the use of lime as a precipitant in the presence of acidic solutions containing sulphates involves the formation of gypsum ($CaSO_4.2H_2O$), a secondary precipitate (Blais, *et al*., 2008; Lin, *et al*.,2005; Baltipurvins, *et al*., 1997). In the production plant where the precipitate is the valuable product, the gypsum contaminates the product and significantly lowers its grade.

3.2 Effect of precipitant type on Copper and Cobalt Precipitation

Results of the precipitation tests conducted to investigate the effect of type of precipitating reagent on Cu and Co precipitation are summarised in Table 4, which shows Cu and Co concentrations of final test solutions and final Cu and Co recoveries. Table 5 shows *c*opper and cobalt metal concentrations during the precipitation process using the investigated precipitant types, namely lime and sodium hydroxide (NaOH). Figures 3 and 4 present both metal concentrations and recoveries obtained with the two types of precipitants. The tests were conducted at ambient temperature, pH 5.5 – 6.0 and residence time of 4 hours. It should be noted that average values of test results are presented for each precipitating reagent.

Results obtained showed that lime was generally more effective than NaOH. The degree of both Cu and Co precipitation was slightly less with NaOH (Table 4). When lime was used as the precipitant an average of 99.85% Cu and 82.21% Co were precipitated; whereas 78.95% Cu and 72.65% Co were precipitated with NaOH. The kinetics of Cu precipitation was high for both lime and NaOH reagents (Figures 3 and 4), while Co precipitation rate was significantly low for NaOH. At the end of the precipitation tests average concentrations were 0.95 ppm Cu and 32.75 ppm Cu for lime and NaOH respectively; while average cobalt concentrations were 12.55 ppm Co and 21.69 ppm Co for lime and NaOH respectively.

It should be noted that at a pH of 5.5 – 6.0 Co precipitation was observed to be lower as cobalt normally precipitates at a higher pH than Copper. The results show that lime is a more effective precipitant than NaOH under the investigated conditions. This can probably be attributed to the fact that Ca^{2+} ions, which have a higher valence than Na^{+}, are more capable of destabilizing negatively charged colloid than Na^{+} ions (O'Melia, 1972). This is in accordance with the Schulze-Hardy rule, which states that the ion that causes a soluble to coagulate is opposite in sign to the electric charge of the colloidal particle; further, the coagulating power increases with the valence of the ion (Trefalt, *et al*., 2020). This is probably one of the reasons why lime is a more effective precipitant than NaOH.

Table 4: Results of tests conducted to determine effect of precipitant type on copper and cobalt precipitation

Precipitant		**Cu conc. (ppm)**		**Cu Recovery (%)**	**Co conc. (ppm)**		**Co Recovery (%)**
	Initial pH	**Test conc.**	**Avg conc.**		**Test conc**	**Avg conc.**	
Lime	1.74	1.50	0.95	99.80	14.20	12.55	82.42
Lime	1.72	1.40		99.91	10.90		82.00
NaOH	2.02	28.8	32.75	81.43	21.19	21.69	73.86
NaOH	1.80	36.7		76.48	22.20		71.43

Precipitation conditions: Feed Solution: 620 ppm Cu, 140 ppm Co, pH 5.5 – 6.0, Test temperature: ambient, Residence time: 4 hours,

Figures 3 and 4 show precipitation kinetics of Cu and Co with lime and NaOH, it can be seen that both Cu and Co precipitation was slightly more when lime was used to adjust the pH. For the tests conducted with lime the concentration of Cu in solution decreased from 620 ppm to an average of 0.95 ppm after 4 hrs, while with NaOH it decreased from 620 ppm to an average of 32.75 ppm. On the other hand, Co concentration decreased from 140 ppm to an average of 10.80 ppm when lime was used. With NaOH the concentration decreased from 140 ppm to an average of 21.70 ppm. It can be seen that the rate of Cu precipitation was generally higher for lime while the rate of Co precipitation was lower with NaOH. Again it was noted that over 95% of Cu was precipitated within 30 minutes and over 70 % of Co precipitated within the same period when lime was used as the precipitant (Figures 3 and 4).

Table 5: Copper and cobalt metal concentrations for Lime and NaOH precipitants.

Residence time (hrs)	Lime Metal conc. (ppm)		NaOH Metal conc. (ppm)	
	Cu	Co	Cu	Co
0	620.00	140.00	620.00	140.08
0.5	4.00	14.65	51.85	125.32
1	2.80	14.20	49.00	84.45
2	1.90	13.40	45.70	72.76
3	1.65	12.30	40.45	46.14
4	0.95	10.80	32.75	21.70

Precipitation conditions: Feed Solution: 620 ppm Cu, 140 ppm Co, pH 5.5 – 6.0, Test temperature: ambient, pH: 5.5 – 6.0, Residence time: 4 hours.

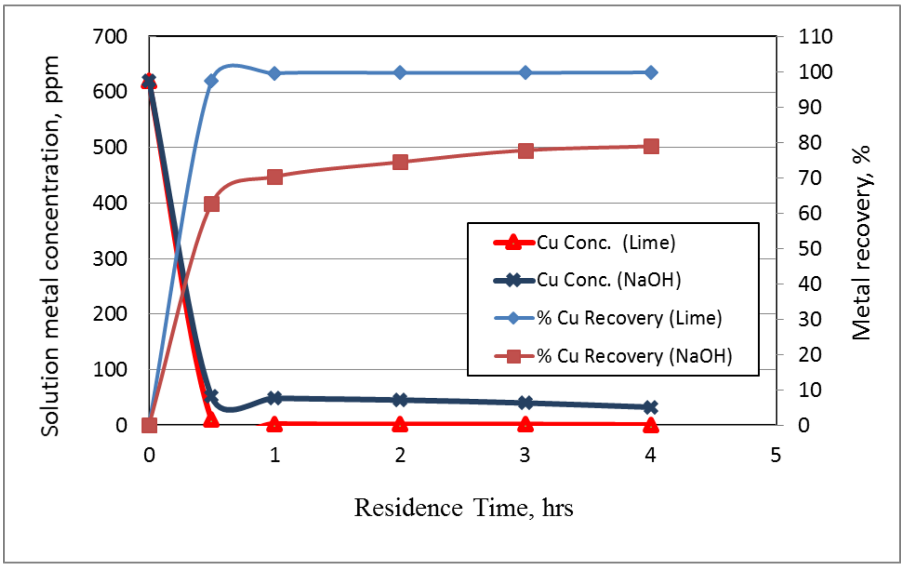

Figure 3: Kinetics of Cu precipitation with Lime and NaOH (pH 5.5 – 6, Ambient temperature, residence time: 4 hrs)

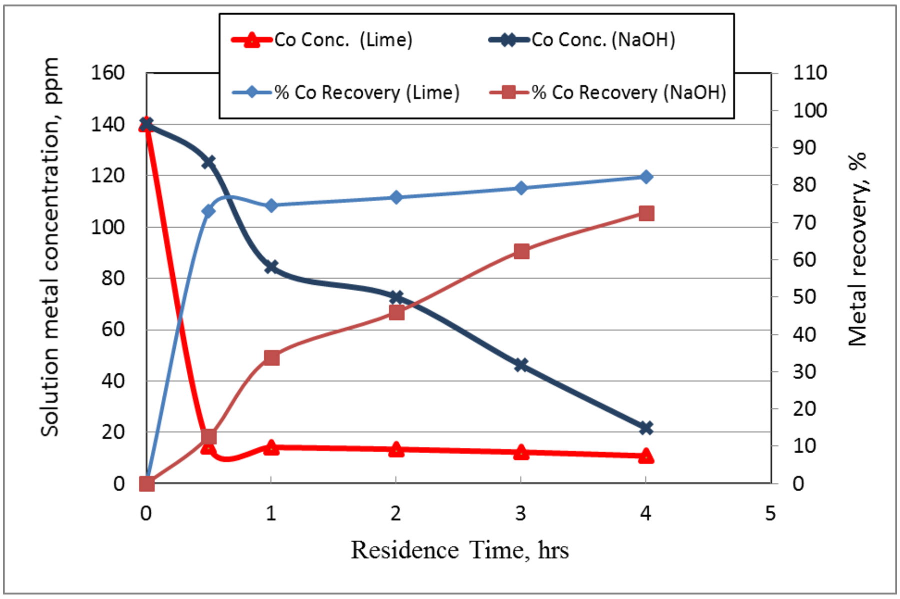

Figure 4: Kinetics of Co precipitation with Lime and NaOH (pH 5.5 – 6, ambient temperature, residence time: 4 hrs)

The precipitation of copper and cobalt by NaOH takes place according to reactions [4] and [5], respectively.

$$CuSO_4\ (aq) + 2NaOH\ (aq) \rightarrow Cu(OH)_2\ (s) + Na_2SO_4\ (aq) \quad [4]$$

$$CoSO_4\ (aq) + 2NaOH\ (aq) \rightarrow Co(OH)_2\ (s) + Na_2SO_4\ (aq) \quad [5]$$

From the reactions above, it can be seen that both copper and cobalt precipitate hydroxides and sodium sulphate; the sodium sulphate may react with the metal hydroxide in solution, which can pause problem to the precipitation process. Apart from the fact that the precipitation product obtained with NaOH is cleaner than that obtained from the use of lime, lime has shown to be an effective and popular precipitant of metals from metallurgical process solutions.

4.0 Conclusion

The present study has shown that copper and cobalt can be recovered from metallurgical process solutions via the precipitation process using lime as the precipitating reagent at pH values above 6 and a residence time of less than 4 hours. Under these conditions more than 90% copper and 70% cobalt can be recovered. Sodium hydroxide proved to be less effective as a precipitating reagent for copper and cobalt under the conditions applied in the present study.

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On bioleaching of Zambian Copper ores

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ABSTRACT

The objective of this study is to assess the possibility of applying bioleaching to copper sulphide ores existing on the Copperbelt Province of Zambia. The study is important because copper is getting depleted resulting in low grade ores hence the need to find alternative viable methods such as bioleaching which is considered to be more economical and environmentally friendly than conventional methods of copper mining. Preliminary experiments were conducted in the Chemical Engineering Laboratory at the Copperbelt University on samples obtained from various sources including KONKOLA ORE, COP F, SP 6 and BSS. The samples were characterised by scanning electron microscope (SEM). Total copper and acid soluble copper were determined on the samples by Atomic Absorption Spectrophotometer (AAS). From preliminary results, KONKOLA ORE contained both Bornite (Cu_5FeS_4) and chalcocite (Cu_2S) while COP F contained chalcopyrite and were found suitable for bioleaching. By the application of bioleaching, 48.95% copper recovery was achieved on tailing samples within 6 days while results for chalcopyrite gave 52.5 % copper recovery within 12 days under un-optimized conditions of bacterial culture to ore ratio of 0.5:1 by mass, pH of 2.7 and temperature of 26 - 30℃. It was therefore concluded that Bioleaching is a viable alternative method and can be employed for the extraction of copper.

Keywords: Bioleaching, *Thiobacillus Ferrooxidans, Thiobacillus Thiooxidans,* Copper sulphide ores, Chalcopyrite, Copper oxide ores.

1 Introduction

The existence of low grade copper ores and tailings has necessitated the use of economical methods of copper extraction as opposed to the use of conventional methods which have proved to be capital intensive (Acevado and Gentina, 2013). Bioleaching is one economical method which can be applied to leaching of low grade copper ores (Akcil, 2004) Bioleaching employs microorganisms for example *Thiobacillus Ferrooxidans* to extract copper and other metals from their ores. Bioleaching presents many advantages because it is both economically and environmentally beneficial not only to the mining industry but also to the nation as a whole (Acevado and Gentina, 2013).

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Bioleaching is suitable for sulphide ores e.g. chalcopyrite but not oxides. Most of the mineral ores that contain copper on the Copperbelt province occur as low grade copper and this has rendered the use of conventional methods of copper extraction which involve drilling, blasting, transportation, crushing, grinding, flotation and smelting uneconomical. Moreover, these methods have not been able to achieve 100% copper recovery efficiency despite being energy as well as cost intensive. Bioleaching is less cost intensive (Wen, *et al*., 2006). These methods have been a subject of concern because they have not been environmentally friendly from various aspects. There are abundant mineral deposits in the country, particularly, on the Copperbelt and North-Western provinces of Zambia and most of these reserves occur in form of sulphide ores. The process of copper recovery also involves smelting which greatly contributes to water and air pollution hence, for low grade ores, there is need to resort to methods that are less capital, less energy intensive as well as environmentally friendly such as bioleaching. It has been reported that leaching of complex ores of lower grade is extremely difficult (Huang and Li, 2014). The need to incorporate bioleaching which can catalyze the leaching process (Shiers, *et al*., 2016), Bioleaching employs microorganisms called *Thiobacillus Ferrooxidans* and *Thiobacillus Thiooxidans* to extract copper and other metals from their ores. Bioleaching is both economically and environmentally beneficial not only to the mining industry but also to the nation as a whole (Acevado and Gentina, 2013). It has been reported that the dissolution of chalcocite progresses in many stages (Trejo-Gallardo, 2007):

$$Cu_2S + 2Fe^{3+} \rightarrow Cu^{2+} + 2Fe^{2+} + CuS \quad (1)$$

$$CuS + 2Fe^{3+} \rightarrow 2Fe^{2+} + S^0 \quad (2)$$

$$S + 3O_2 + H_2O \; \textit{bacteria} \rightarrow 2H_2SO_4 \quad (3)$$

Bioleaching can also be used to enhance the extraction of valuable metals from their ores and this can contribute greatly to the economy of the country (Borja *et al*., 2016)**.**

1.1 Theoretical and Conceptual Framework

Certain microorganisms such as *Thiobacillus Ferrooxidans* and *Thiobacillus Thiooxidans* are reported to possess the ability to cause dissolution of metals from their sulphide ores naturally by consuming iron and sulphur from them (Ilyas, *et al*., 2010) therefore, a concept can be developed for a technique based on the nutritional characteristics of these microorganisms to leach copper from its sulphide ores in a process that is called bioleaching which can be represented by the following equation involving chalcopyrite (Wang, *et al*., 2014)

Thiobacillus ferrooxidans and *Thiobacillus thiooxidans*

$$\mathbf{4\ CuFeS_2} \longrightarrow 4CuSO_4 + 4Fe(OH)_3 + 8S \quad (4)$$

$$\mathbf{4\ CuFeS_2} \longrightarrow 4Cu^{2+} + 4Fe^{3+} + 8S^{6+} \quad (5)$$

If various conditions are optimized, bioleaching can be used to accelerate the dissolution of copper from its sulphide ores. Therefore, it is envisaged that if various conditions including pH, Temperature, speed of agitation (rpm), bacteria to ore ratio and pulp density are optimized, the bioleaching process can be greatly accelerated with the result that large yields of copper can be recovered in as short a period of time as possible. In this process, particle size is important because it affects the kinetics of bioleaching (Ahonen and Tuovinen, 1995). Another parameter of particular importance is pulp density which significantly affects the rate of bioleaching (Pradhan, *et al.*, 2008).

2 Materials and Methods

2.1 Sample characterization

First of all screen analysis was conducted on samples with sample identities: KONKOLA ORE containing both Bornite and chalcocite and COP F containing chalcopyrite were first subjected to screen analysis by screens of various sizes and various particle size distributions were obtained to 45, 75, 106, 212, 710 and 850 µm. The results were tabulated and graphs were plotted. Secondly, mineralogical examination of the samples was conducted. The samples were characterized by using scanning electron microscope (SEM) equipment and several images of ores were reported.

2.2 Bioleaching of Tails:

- 10 g of tailings of particle size 212 µm passing was weighed and placed in each of 3 beakers labelled A, B and C.
- Beaker A was boiled at 100 ^{o}C for 1 hour in order to kill the microorganisms and no bacterial culture was added.
- Beaker B was not boiled and no bacterial culture was added
- Beaker C was not boiled and bacterial culture was added.
- The samples were acidified with small portions of H_2SO_4 and NaOH to attain a pH of 2.7 and were agitated continuously using the mechanical shaker for a period of 20 days within the temperature range of 26 -30℃ while continuous shaking was achieved using the mechanical shaker
- The percentage of copper leached was determined daily using the *AAS* and the percent Copper recovery was calculated.
- The samples were left to stand for 26 days.

2.3 Bioleaching of Chalcopyrite:

- 1 g of chalcopyrite of particle size 212 µm passing was weighed in a beaker and some bacterial culture was added.
- The sample was acidified by adding small amounts of H_2SO_4 and NaOH to attain the pH of 2.7.
- The sample was left to stand for 20 days at a temperature range of 26 -30℃. Aeration of the samples was done by regular shaking using the mechanical shaker in order to ensure the bacteria were exposed to oxygen.
- The beakers were left standing with regular shaking for 20 days.

- The percentage of copper leached was determined daily using the *AAS* and the percent Copper recovery was calculated.

3 Preliminary Results:

3.1 Sample screening of KONKOLA ORE:

Table 1: Sample ID Konkola ore

Screen size	850	710	212	106	75	45	0
Cum wt% passing	75.7	72.4	51.5	38.3	30.6	20.6	0

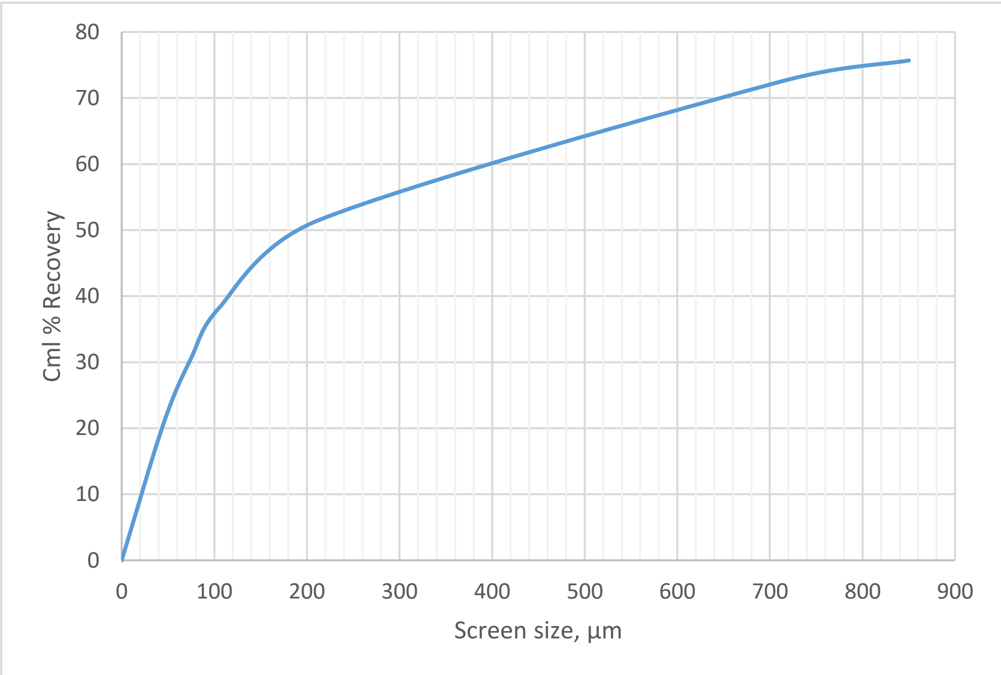

Fig. 1: Cumulative % weight passing v. screen size for Konkola ore

3.2 Mineralogy of KONKOLA ORE

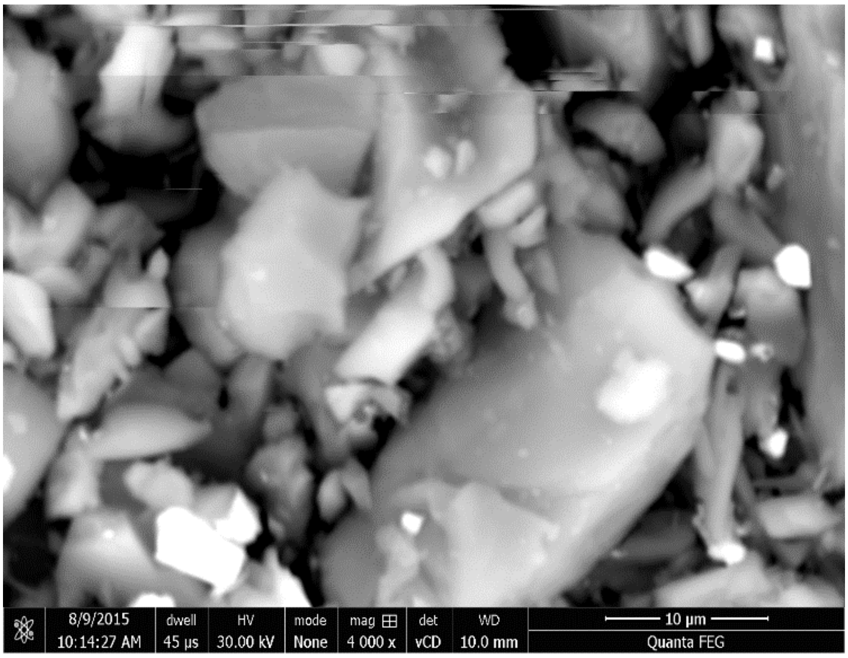

Fig. 2: Image of Konkola ore revealed by scanning electron microscope (SEM)

3.3 Sample screening of COP F

Table 2: Sample ID Cop F

Screen size	850	710	212	106	75	45	0
Cuml wt% passing	69.9	66.1	38.2	28.3	23.0	15.4	0

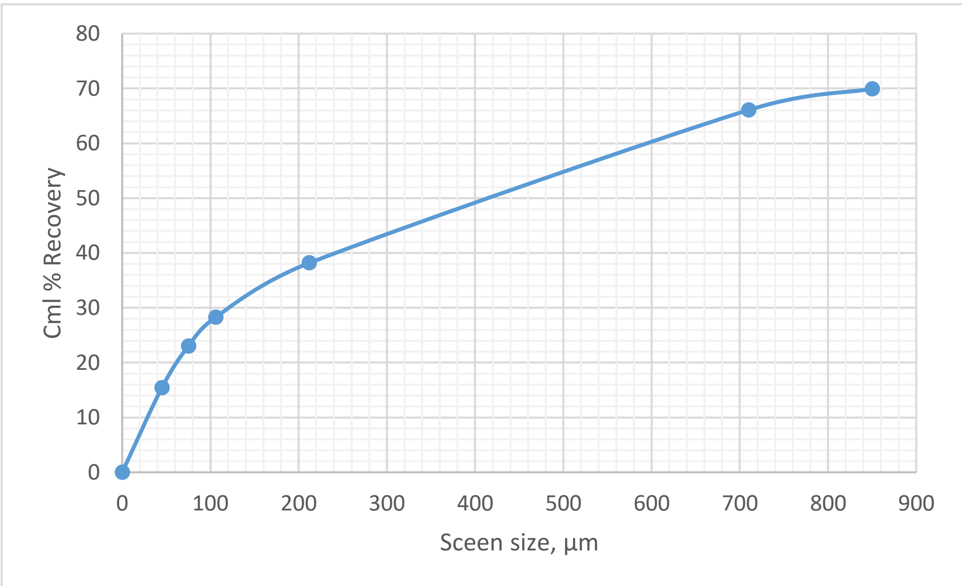

Fig. 3: Cumulative % weight passing v. screen size for sample Cop F

3.4 Mineralogy of COP F

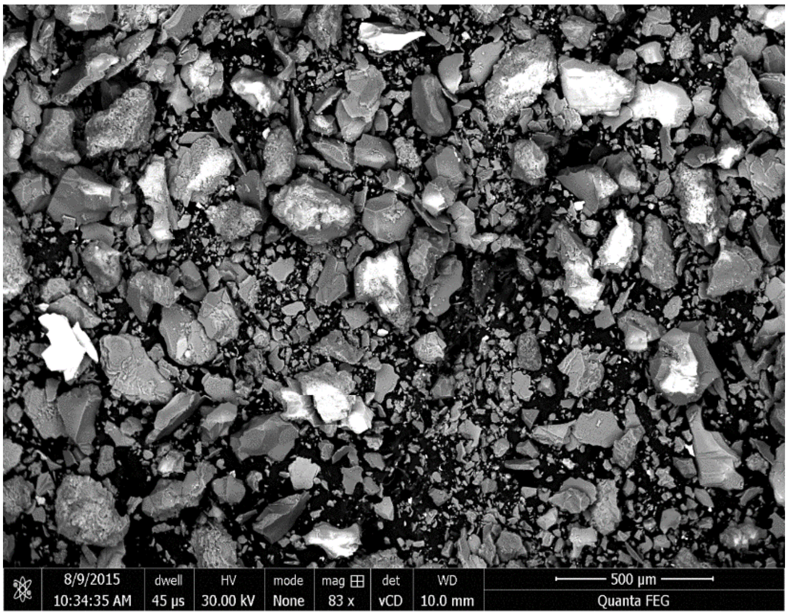

Fig. 4: Image of Cop F revealed by scanning electron microscope (SEM)

Table 3: Sample Characterization

	Type of Ore	**Types of Mineral phases**
KONKOLA ORE MIX	Sulphide ore	Bornite (Cu_5FeS_4) and chalcocite (Cu_2S)
COP F	Sulphide ore	Chalcopyrite ($CuFeS_2$)
SP 6	Oxide ore	Malachite ($Cu_2CO_3(OH)_2$)
BSS	Mixed ore	Malachite ($Cu_2CO_3(OH)_2$) and Chalcopyrite ($CuFeS_2$)

Table 4: Chemical composition showing overall compositions of all the samples

	Cu	**Co**	**Fe**	**S**	**Ca O**	**SiO2**	**Al2O3**	**Mg O**	**K_2O**	**MnO_2**
KONKOLA ORE	2.57	0.00	4.22	1.24	5.31	49.82	18.91	6.33	7.56	0.82
COP F	1.47	0.01	3.79	0.28	4.82	62.89	14.16	5.02	5.04	0.00
SP 6	2.44	0.01	4.05	0.02	0.00	54.53	24.54	6.86	2.80	0.12
BSS	1.23	0.01	4.58	0.14	3.89	52.04	16.28	11.67	4.51	0.13

3.5 Results for application of bioleaching on tailings and chalcopyrite using native microorganisms

Fig. 5: Left to right: beaker containing bacterial culture, beaker A, B and C on the first day

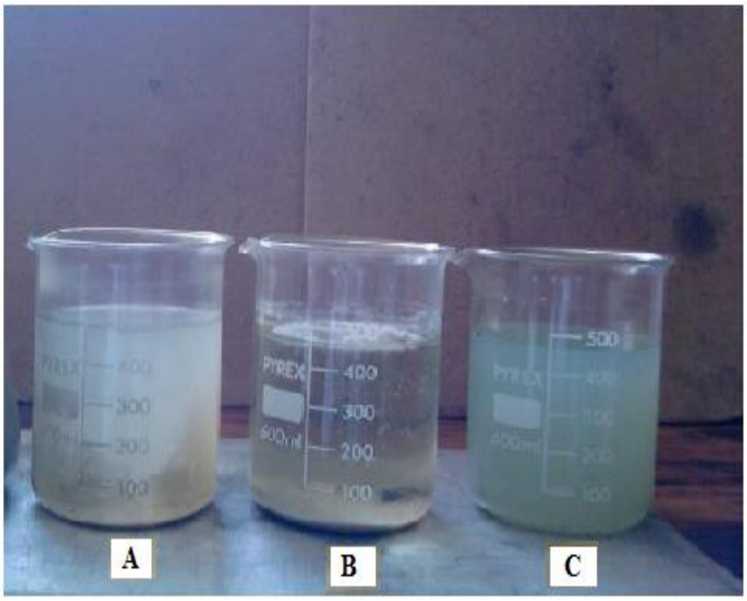

Fig. 6: Colour of solutions (from tails) after 14 days of bioleaching

After 14 days a bluish colour was observed in beaker **C** containing bacterial culture indicating that bioleaching of copper was taking place because bacteria from the culture and from the ore were alive and active. In beakers A and B, no colour change was observed indicating that there was no bioleaching taking place in **A** as the bacteria had been killed due to boiling while **B** contained no bacterial culture and the little copper leached was due to a few native bacteria present in the ore.

Table 5 is the table of copper analysis results for the bioleaching of tailings at 26 - 30℃, and pH 2.7 from day 1 to day 26 by AAS (each beaker contained 10 g of old tailings in 200 ml solution).

Calculations:

- **For Tailings:**

Initial % Cu content in tails less ASCu = 0.4% Cu

% Cu recovery = (% Cu leached / initial % Cu in tails) x 100

3.6 Bioleaching of Tailings Results

Table 5: % Cu recovery from tailings by AAS

Sample	Status	1	6	11	16	21	26
A	Boiled tailings	25.45	25.45	25.45	25.45	25.45	25.45
B	Unboiled	25.45	46.45	47.3	49.05	49.45	50.3
C		25.45	48.95	47.3	51.05	55.45	67.95

The results can be plotted on the graph, as given in Figure 7.

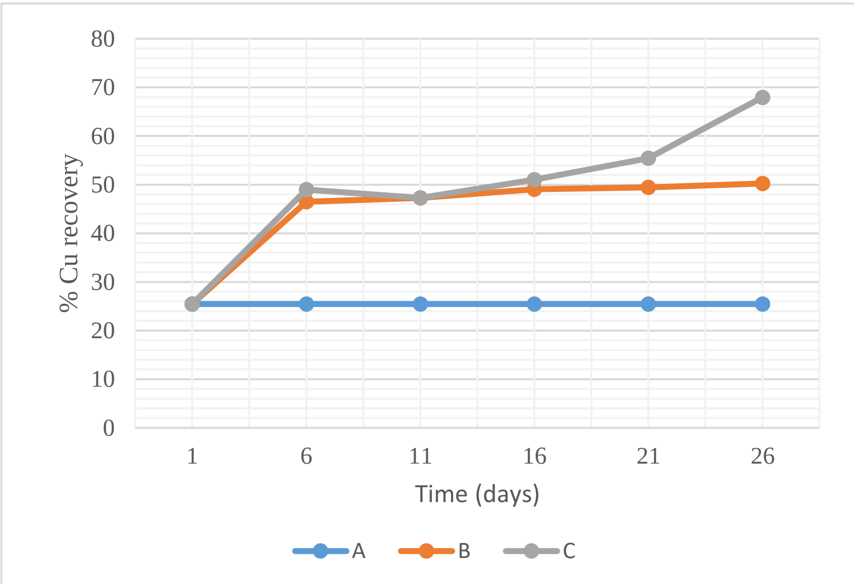

Fig. 7: graph of % Cu recovery from tailings versus time (days)

From the results in Figure 7, sample A which had initially been boiled did not indicate any variation in copper leached which remained constant at 0.10 % representing 25 % of Cu recovery from day 1 till day 26 caused by acid leaching only. Sample B revealed slight increase in copper leached from 0.10 on day 1 to 0.20 % copper leached by day 26 representing 50 % copper recovery brought about by native bacteria present in the tailings. Sample C showed the highest % copper leached amounting to 0.27% representing 67.95% copper recovery because of the bacterial culture which had been added to the sample indicating that bioleaching can be enhanced greatly by using the bacterial culture.

3.7 Bioleaching of Chalcopyrite Results

Table 6: % copper analysis results for chalcopyrite

No. of days	2	4	6	8	10	12	14	16	18	20
% Cu recovery	2	12	25	53	22	18	17	26	19	18

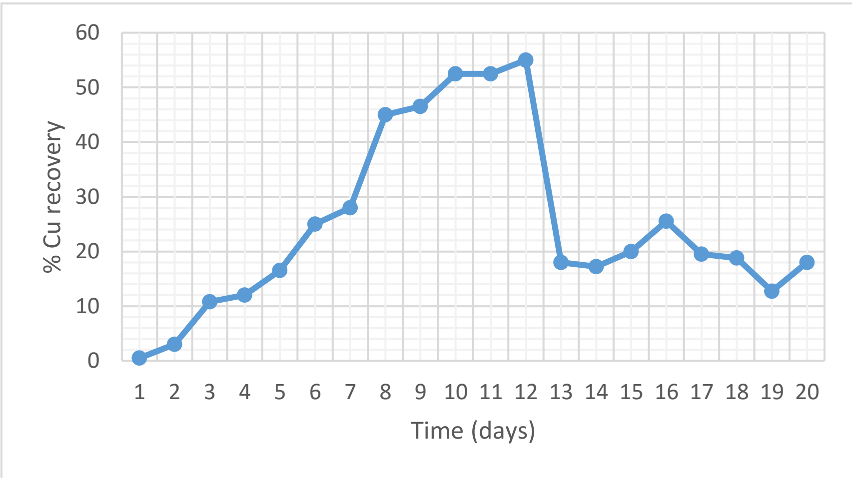

Fig. 8: Graph of % Cu recovery from chalcopyrite versus time

As observed in Figure 7 for % Cu Recovery from Tailings versus Time, the graph for sample A which had been boiled, it is evident that the bacteria in sample A had died due to boiling and the only little copper that was leached was due to acid leaching, that is, 0.10 % copper leached and it remained constant up to day 26. For sample B which was not boiled, the bacteria were alive and were responsible for copper leaching and hence a much higher result of 0.20 % of copper leached which was higher than for A was recorded. Sample C recorded the highest amount of copper leached at 0.27 % which was higher than for both A and B due to the addition of the bacterial culture, hence it can be concluded that bio-leaching can be enhanced due to the presence of bacteria. The results for sample B and C consequently annul the notion that copper leaching could have been solely caused by acid leaching.

As observed from Figure 8 involving the bioleaching of chalcopyrite, the curve rose from 0.0 % copper recovery on day 1 to the peak at 52.5 % copper recovery on day 12 and then dropped suddenly to 18 % on day 13. The graph rose again slightly to the second peak of 26 % copper recovery on day 16 which was lower than the first peak. After day 16 the graph continued dropping to a minimum of 12.5% on day 19. This development had not been anticipated before. However, this indicates that further investigation is required. There were two lines of thought for this fluctuation in the curve:

(1) The first possible reason was that the drop in the % copper recovery was caused by reduction of Cu^{2+} ions due to the high concentration of Fe^{2+} ions present in solution as the latter is more electropositive than the former in the electrochemical series thereby causing the reduction of Cu^{2+} ions. This implies that it was important to optimize the Redox potential between Cu^{2+} and Fe^{2+}.

(2) The second possible reason was that the bioleaching reaction does not proceed directly from reactants to the final products but proceeds through several intermediate reactions as indicated by many peaks. At some point, there is even a reversal in the bioleaching process.

4. Conclusion

The following results were obtained after the application of bioleaching: tailings gave a copper recovery of 48.95% in 6 days while chalcopyrite gave a copper recovery of 52.5 % in 12 days. Both experiments were conducted under un-optimized conditions of pH 2.7; Temperature 26 - 30℃ and Bacterial culture: Ore ratio 0.5:1. From the results obtained, it was concluded that bio-leaching of copper from tailings and its sulphide ores is a viable alternative method and can be employed for the extraction of copper.

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Application of Risk Management in Airport Construction Projects in Zambia – Case of New Copper belt International Airport

Daniel Chileshe Musantu[1]

Abstract

This research focuses on the identification of risks and application of risk management concepts specifically on airport construction project in Zambia. The ultimate goal of the research was to propose a risk management framework in airport construction projects upon discovering there was none in existence. The study was also to propose improvements to the current risk management framework upon discovering there was one in place and had gaps and flaws.

According to International Civil Aviation Organisation (ICAO), there has been an increase in aircraft movement worldwide. Such rapid growth has not spared Africa and requires the construction and expansion of Airports and their associated facilities such as Passenger Terminal, Cargo Terminal, etc.

Airports design and construction are one of the complex projects due to their tremendous amount of information flow in all design stages, dealing with the various disciplines involved in Airport projects, managing the variety of stakeholders involved in the project in all stages, and dealing with the complexity of design and implementation of the project

Specifically, this study used the stakeholder theory to analyze the various stakeholders associated with airport construction projects. In-depth interviews were conducted and questionnaires were administered to practitioners who are currently involved in the Copper belt Airport construction project. Descriptive statistics were employed to analyze data for the study. Economical and financial risks were ranked at the very top of the list in terms of mean average and significance score. The findings of the study showed that risk management concepts were not fully utilized on the Copper belt Airport project. A Risk Management Framework was developed and recommended by the researcher for adoption in Zambia for airport construction projects.

Keywords: Risks, Risk Management, Airport Construction Projects

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1 Introduction

Governments in many developing countries are working very hard to achieve their social and economic sustainable development objectives (Human Development Report, 2011; Zeybek and Kaynak, 2006; Cohen, 2006). And this can only be achieved through constructing infrastructure, industrial, educational, cultural, transportation, medical, and residential facilities that provide societies with their needs and fulfill their requirements (Othman, 2012; Khan, 2008; Mthalane et al., 2007; Field and Ofori, 1988). Usually, such undertakings are complex, risky, and time-consuming and require proper management. (Ezzat Othman 2013). According to Sanvido(1992) construction industry operates in a very uncertain environment where conditions can change due to the complexity of each project. (Gajewska and Ropel, 2011). To archive economic sustainable development most governments have invested huge sums of money into construction projects such as airports. For example, the Zambian government has invested a lot of money in the expansion and modernization of the Kenneth Kaunda International Airport in Lusaka and in the construction of the new Copperbelt International Airport in Ndola. (National Budget 2018).

Airports design and construction are one of the complex projects due to their tremendous amount of information flow in all design stages, dealing with the various disciplines involved in Airport projects, managing the variety of stakeholders involved in the project in all stages, and dealing with the complexity of design and implementation of the project

Airports are significantly affected by increased demand. Forecasted growth calls for an increase in airport capacity, no small task given the long lead time, costs, political conflict, and logistical challenges related to expansion options. Creating airport capacity to meet future demand has been cited as "the biggest challenge in the present decade for airports and airlines." (Lutte and Bartle 2017). And huge sums of money are being Investment in international airport infrastructure worldwide, approximately US$750 billion was to be spent before 2020 worldwide. (Lopez et al. 2017).

The Zambian government attaches great value to the development of the airport infrastructure as can be seen in the Seventh National Development Plan (7NDP). The 7NDP mainly focuses on the construction and upgrading of airport infrastructure to provide modern equipment and facilities which will enable the country to handle higher volumes of traffic, both passengers and cargo. Provincial and strategic airports will also be upgraded to increase the capacity to handle more traffic (MNDP 2017).

Currently, two airport construction projects are ongoing in Zambia one in Lusaka and the other one in Ndola. Kenneth Kaunda International Airport in Lusaka is being expanded to handle 4 million passengers per annum at a cost of US$391 million. A Greenfield Airport is also being constructed in Ndola at an estimated cost of US$397 million with a terminal capacity of 2 million passengers per annum. The works for Copperbelt Airport will include the terminal building, office complex, a hotel, an airfield, access roads, and a fuel farm (MNDP 2017).

Airports are becoming as important as seaports in this role of attracting economic development. National and regional economic development require transportation infrastructure. Infrastructure may not directly result in development, but the fact remains that it is a prerequisite for any sustained economic development(Zografos, Madas, and Androutsopoulos 2017).

1.1 Statement of Problem

Airport construction projects are usually complex, costly, and are associated with a high degree of risk due to the nature of construction business activities and processes (Akintoye and MacLeod 1997). When projects fail, the damage to the funders and the users can be massive (Akintoye and MacLeod 1997). The Berlin Brandenburg Airport project is one of a high profile failure being more than 4 years behind schedule and at least 70% above budget. (Case and Airport 2015). Risks are typical reasons for delays or cost overruns that can occur in a project. As a result, many time delays and cost overruns are found among different Saudi aviation construction projects' good example is the new King Abdul Aziz International Airport in Jeddah delayed its completion (Baghdadi and Kishk 2015). Project managers and Engineers executing such projects make sure that these projects are delivered successfully. However, it has been observed worldwide that there is a high rate of failure of airport construction projects. The challenge of airport projects not being delivered within schedule, recording budget overruns, and not meeting the required quality of works is somehow a result of lack of good application of risk management of the projects in Saudi Arabia(Baghdadi and Kishk 2015). In a development report by the World Bank, it is stated that if risk management is well implemented on infrastructure development projects, the project success rate increases, while decreasing negative outcomes (Adiga et al. 2020).

2 Research Objective

The main objective of the research is to examine how effective risk management is applied in Airport Construction Projects. Therefore, develop a risk management framework specifically for airport construction projects in Zambia.

These specific objectives were set:

a) To identify the risks associated with the Construction of the New Copper Belt Airport Project. a.

b) To examine the probability of risk occurrence and the impact on the New Copper Belt airport construction project. E.g. political risk

c) To develop a framework to enhance risk management application on Copper belt Airport Construction Project and also for other airport projects in Zambia. The framework will involve decision-making elements and actions to correct project failure rates.

3 Literature Review

Globally Improvements in the air transport infrastructure have a key role to play in the improvement of national socioeconomic and living standards. Air transport results in many benefits including freedom of movement, enhanced productivity, trade, and tourism (Lutte and Bartle 2017). Airports are becoming as important as seaports in this role of attracting economic development. As National and regional economic development require transportation infrastructure (2000) In United States, many airports are looking forward to expanding their capacities depending on the Federal Aviation Authority (FAA)'s plan to modernize the National Airspace System over 2025 (Afrian et al. 2017).

Airports are the gateways providing the international connections that Zambia needs to grow and prosper. Zambia, being land-linked, is an outward-looking nation that owes its prosperity to peaceful co-existence with its neighbours. With the increasing globalization of its economy and society, the future of Zambia will undoubtedly continue to be shaped by the effectiveness of its international transport networks(MNDP 2017). The airport industry is a very large investment with a high level of impact on a region's and national economies and development. Despite some scholars rating the aviation industry to be very significant in national development some scholars have considered other modes of transport to be very important and must be prioritized in terms of capital investments. Funds spent on air transport infrastructure can often better promote development by being directed to other modes of transport especially in developing counties. For example, Mwila (2016) considers rail transport to be critical in the development of third-world countries like Zambia. With its inherent advantage of being a bulk carrier, safer and cheaper, rail transport is an important cog in intermodal transportation. It is also more environmentally friendly, has less congestion, and has a better fuel efficiency than other modes.

3.1 Study Theories

The main objective of a theoretical framework is to ensure that a structured approach is used to identify significant success factors. The study theoretical framework was founded on theories related to the construction industry which enabled the development of research. The contingency theory, stakeholder theory, and management theory provide such a structure because construction projects are characterized by many risks. In this study, the researcher compiled the following theories which were later used as a guide for the research investigation of the findings.

4 Risks Associated With Construction Projects

Worldwide large and complex infrastructure projects such as airport constructions can be associated with various risks. These risks can be identified at the design, construction, and completion stages of the project. Mainly most of the risks associated with a construction project are given the name PESTLE about the acronym formed by the initials of the six categories of macroeconomic variables included in the model (Political, Economic, Socio-cultural, Technological, Legal and Environmental) (Planellas and Muni 2019). Figure 1 below highlights the common risks associated with construction projects.

Based on these risks it is important to isolate and assess the critical risk factors for International Airport Construction Projects. The successful implementation of such huge projects depends on the effective management of the key risk factors.

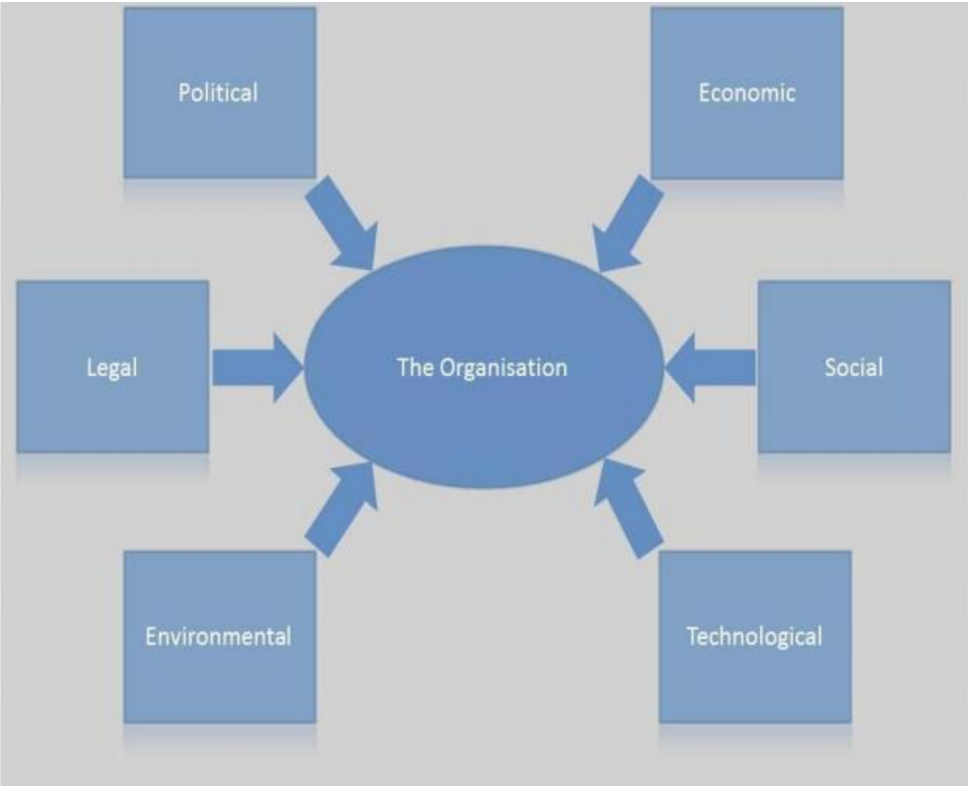

Figure 1: Risk analysis diagram (Source: Hussain (2013))

4.1 Study Population

Questionnaires were used to target a population of 60 professionals from the six strands indicated in table 1. All study respondents were involved in airport construction projects within Zambia.

Table 1: Sampling Frame

S/N	Study Population	Sample size
1	Consultants	4
2	Contractors	4
3	Project Managers	4
4	Stakeholders	9
5	Engineers	22
6	Clients	9
	Total	**52**

Formulated by Author (2020)

The survey carried out brought out the risks associated with the Copper belt International airport construction project. The study aimed to find out from contractors, project management practitioners, and experts their perception of the risk management application in airport construction projects in Zambia. The study identified 25 risks associated with airport construction.

5 Identification Of The Risks Associated With Airport Construction In Zambia

The first objective of this research was to identify the risks associated with airport construction projects through a literature review as secondary data. And also by collecting primary data from experts in airport construction projects in Zambia by using a questionnaire survey. Airport construction risks vary according to a country's political, economic, resources, and technological issues as well as social conditions (Hasani and Abdullah 2019).

The first research objective was to identify the relevant risk factors in airport construction projects in Zambia. The risk factors were identified and categorized through a process of reviewing the relevant literature followed by the questionnaire survey that targeted experts in aviation projects. 25 risk factors were identified from the literature review and were classified based on their sources. And these 25 risk factors (RF) were grouped under 7 categories, namely: (1) Client related risks, (2) Risks due to poor Coordination between working parties, (3) Design, Specification, Estimation, and Scheduling Risks, (4) Contractual Risks 5) Financial and Economic Risk, (6) Political, Regulatory and Bureaucratic Risks and (7) Force Majeure, Environmental, Quality Risk, and Social Risk. In conclusion, financial and economic risks scored the highest under risk identification . Most respondents strongly agreed to financial and economic-related risks.

The second objective is "to examine the risk probability and impact on airport construction projects in Zambia. This section deals with the results from analysing the questionnaires, and discusses these results against the results from similar studies. By use of literature review and primary data from field surveys 25 risks were identified that are assumed to be associated with airport construction projects. And they were ranked according to the probability of occurrence and impact. Further, these risks were classified into 7 categories. The following are the 7 risk categories:

1) Client related risks
2) Contractual and Poor Coordination
3) Design, Specification, Estimation, and Scheduling Risks
4) Financial and Economic Risk
5) Inadequate knowledge, Skills, and Experience
6) Political, Regulatory, and Bureaucratic Risk
7) Force Majeure, Environmental, Social, and Quality Factors

6 Airport Construction Risk Management Framework

The third and final objective of this study was to develop a risk management framework for the Copper Belt International Airport project and also be adopted for other airport construction projects in Zambia. As highlighted in the statement of the problem. The interviews also revealed that the risk management framework is weak in Zambia. The assumption is that when risks inherent in airport construction projects are adequately identified and managed. This would promote economic growth and national development. Although the current mitigating strategies used in risk management were mentioned during the interviews, the strategies exhibit failures to maximize the risk management framework.

The risk management framework is important to Successful and effectively manage risks on projects (Fadun 2013). The proposed research risk management framework for airport construction projects is derived directly from conceptual and theoretical analysis, qualitative (interviews) findings, and quantitative findings. This framework is composed of coherent concepts and organized in a manner that makes them interact in order to enhance the risk management process in order to achieve project success. The project should be delivered within, stipulated schedule, cost, and meet their specifications. The success of a project is determined by time, cost and quality, and the end of the project (Akintoye and MacLeod 1997).

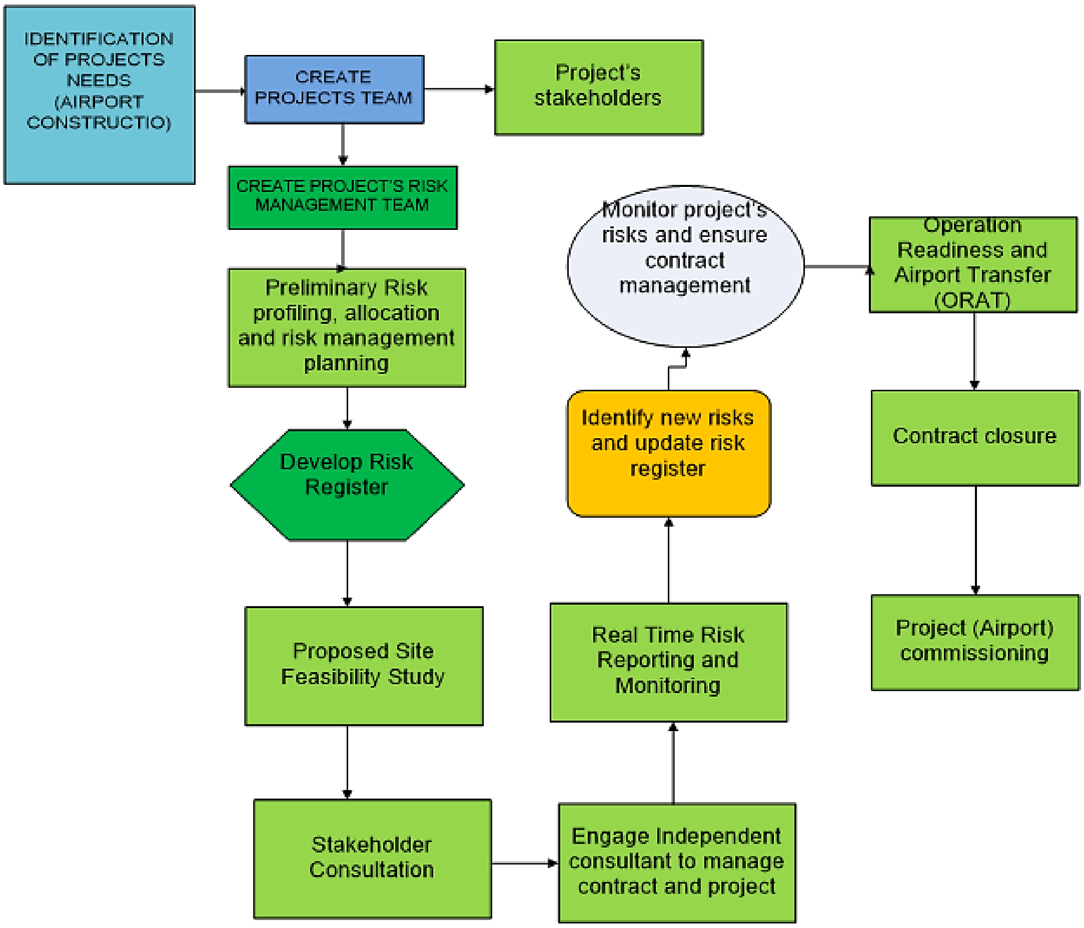

Figure 2: Airport construction risk management framework

The model was presented using a flow chart as it is a useful tool for communicating how processes relate to each other. It is also easy to understand and explain the steps involved in the systematic process. The manual for the proposed model is provided in the appendix. The first stages framework emphasizes the stakeholder engagement and creation of risk management teams from all the stakeholders to represent their interest at the design stages of the projects. The second part is the risk identification process through the creation of a risk register. The third part is the monitoring and reviewing of risks at all stages of the airport construction project cycle.

7 Research Recommendation Future

This study has looked into risk management from the perspective of all stakeholders in the airport construction project. Future research should focus on risk management from the perspective of consultants, sub-contractors, contractors, and clients. It is necessary to identify risks at different stages of the project lifecycle. Different risk factors influence airport construction projects at different development stages with varying probability and consequences.

8 Conclusions

As the Zambian economy grows, it demands quality infrastructure such as airport infrastructure for they contribute to national development. Therefore, the quality of such infrastructure should stand the test of time. This study has proposed specific ways to enhance the future delivery of airport construction projects. It is hoped that the results of this research will spurn conversations that will change the risk management application on airport construction projects in Zambian.

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SEM Analysis of Aggregate Packing and EDS Analysis of Elemental Composition of Concrete Composites

Thimothy Thamae[1], Antoine Mulaba-Bafubiandi[2]

Abstract

In concrete construction, packing of aggregates and selection building materials of composites are some of the most important challenges. This is true in the case of emerging high-end engineered stone and terrazzo concrete composites. Assessment of material selection and aggregate packing mechanisms on these specialised forms of composites is still rare in literature. The study seeks to understand material selection and aggregate packing mechanisms of selected commercial grade terrazzo and engineered stones. The samples were subjected to Scanning Electron Microscopy (SEM) and Energy-Dispersive X-Ray Spectroscopy (EDS) to better understand aggregate packing used and the elemental composition of both the continuous and discrete phases of the composites. Quartz is the main aggregate of choice in the composites due to its hardness. Cementitious matrices with evident infusion of pozzolanic powders and polymeric plasticisers are used for terrazzo composites while polymer matrices are selected for engineered stones evidently due to their extreme toughness. Aggregate packing involves a careful selection of coarse, medium and fine aggregates in the case of terrazzo composites while it involves the use of aggregates of highly polarised diameters to achieve the highest possible degree of aggregate packing in the case of engineered stone composites. The latter is the best possible aggregate packing mechanism although it might be costlier.

Keywords: Aggregates, Packing, Terrazzo, Engineered Stones, Scanning Electron Microscopy, Electron Dispersive Spectroscopy

1. Introduction

In concrete-based composite design and construction, packing of aggregates is one of the most important challenges (Baulea and Makse, 2014, Li and Kwan, 2014, Ghasemi and Emborg**,** 2019). An ideal concrete mix is that in which the discrete phase— aggregates such as the coarse, medium and fine, leave as little interstices as possible, in which case such interstices are filled by a matrix (the continuous phase), usually Ordinary Portland Cement (OPC) in the case of products like terrazzo composites and polymer resins in the case of engineered stone composites. Ideally, good aggregate packing can be achieved by ensuring a mixture of fine and coarse aggregates in right proportions such that fine aggregates fill the interstices left by coarse aggregates (Mohammed *et*

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al, 2012). In that arrangement, properties of concrete are improved, including dimensional stability, compressive strength and durability (Mangulkar and Jamkar, 2013.

In the real world, achieving an ideal mix of aggregate diameter sizes is easier said than done. That is because assumptions often made in packing theories ignore real-world factors such as variances in particle shapes, sizes and overlapping in these attributes between the fine and coarse aggregates. In fact, the prevalence of aggregate packing models claiming to solve the same problem for more than a century have let some to question whether packing theories are not more of art than science (Mohammed *et al*, 2012, Goltermann *et al*, 1997). The first aggregate packing models in concrete were developed as early as the 19th Century and published studies appeared in the 1930s (Mangulkar and Jamkar, 2013). At the heart of these models is the supposition that interstices naturally left between coarse aggregates can be ideally filled up by finer aggregates of the right size. The right size means that the finer aggregates do not go beyond the size of the interstices left by the coarse aggregates, thereby not upsetting the close packing arrangement of the coarser aggregates (Xianjue, 2018).

In the case where fine aggregates have more volume than course aggregates, the so-called walling effect in which fine particles dislodge each other in the vicinity of a coarse particles interspersed within them has been assumed (Xianjue, 2018). The real-world observation has been that coarse aggregates are often interspersed between a matrix of fine aggregates and not often the other way round—where matrix in this case does not mean a binder such as a polymer resin or cement but a mixture of a binder with fine aggregates (Mamirov, 2019). In addition, the problems with some of the best models developed over time resulted on assumptions found to be the following by Goltermann *et al* (1997) which go contrary to reality in practical applications: (a) aggregates are perfect spheres (Mangulkar and Jamkar, 2013), (b) aggregates are mono-size, and (c) fine and coarse aggregates do not have overlapping sizes. By introducing the concept of the characteristic diameter of the aggregates (Alderliesten, 2013), the first two problems were addressed by Goltermann *et al* (1997) in what they called modified Toufar model. The last problem is often considered insignificant in most cases (Mamirov, 2019)). The modified Toufar model was seen to correlate closely with 800 experimental results which gave a high degree of confidence (Goltermann *et al* (1997).

It must be noted that while these aggregate and matrix selections and packing models are normally concerned with physical and of course, cost (the lower the matrix used in good packing result in lower cost) properties of composites, they rarely touch on the impact of such selections and packing on the aesthetics of concrete That is because the commercial application of these composites for application in terrazzo and engineered stones barely receive any attention in academic literature (Suta *et al*, 2019). In these applications, beyond minimum physical properties which in the case of low-end terrazzo, are often protected by periodic application of sealants, the main properties that matter to the consumers are often such things as shininess and texture, which, despite being overlooked in academia, may as well determine growth or bankruptcy in the commercial world (Santos *et al*, 2019). What is more interesting is how related to the science of packing such aesthetic properties are. For instance, in the area of engineered stone and high-end terrazzo tiles, putting a cap on the characteristic diameter of the coarse aggregates is more likely to attract customers than tiles with randomly selected aggregate diameters. If polishing of the tile surface is involved, the close packing of the particles creates a huge difference in terms of whether the tiles are seen as concrete or natural stone in the market. The idea is to influence the customer to see the latter, despite the fact that such as customer is basically experiencing the former. That is because high packing degree leads to very high aggregate-to-cement ratio (Sonja *et al*, 2009) which in turn, leads to a “hidden” existence of cement in the composites. In fact, some natural sandstones use the same principle in which a natural matrix is there but barely visible.

The objectives of this study are to analyse the composite composition and aggregate packing of selected terrazzo and engineered stone composites in order to determine the following: (a) the choice of materials used and the rationale behind such choices and (b) the kind of packing mechanism used and the rationale behind the packing.

2. The Methodology

Three commercial grade samples were selected (Figure 1). These three samples fit the description of terrazzo for the first two and that of engineered stone for the last. Terrazzo composites normally have an inorganic binder such as cement while engineered stone aggregates are bound by thermosetting polymers. Sample 1 and Sample 2 consisted of Portland cement matrix, additives and quartz aggregates to make a composite body. Sample 1 had a lighter colour and bigger aggregates. Sample 3 was an engineered stone body made from an organic polymer resin, additives and quartz aggregates. Properties of these materials were not availed by manufacturers. Since these were commercial scale samples, ratios of aggregates to binders were also not made available. However, such unavailability did not prejudice the objectives of the study. The samples were cut with an electric diamond saw to sizes small enough to fit subsequent observations to reveal the primary surfaces of the samples. The Scanning Electron Microscope (SEM) model TESCAN Vega 3 XMV with a detector Oxford X-Max and with an Electron Dispersive Spectroscopy facility were used to analyse the cut and exposed surfaces. The SEM generated micrographs of the surfaces of interest and the EDS measurements provided localised elemental analyses.

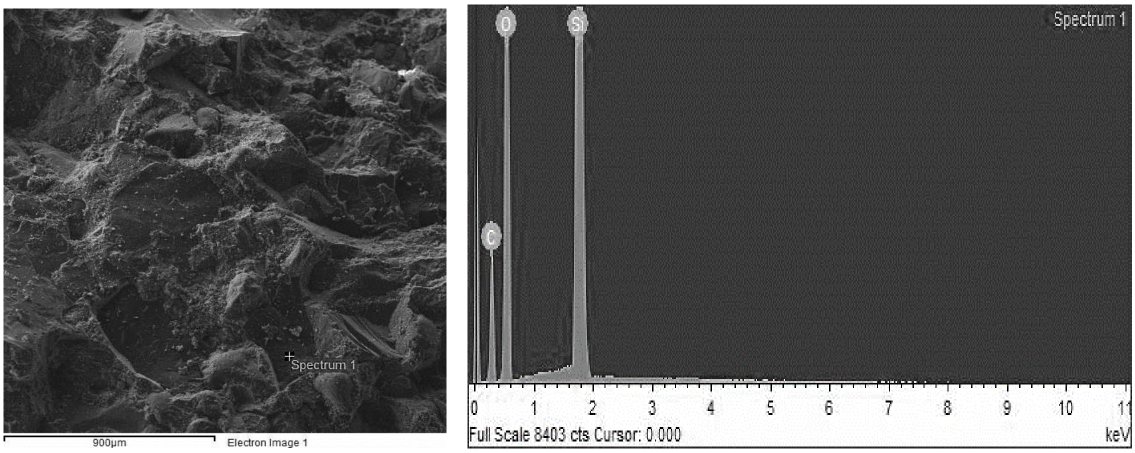
(1) (2) (3)

Figure 1. Photographs of samples 1 to 3

3. Results and Discussions

3.1. Composition of the composites

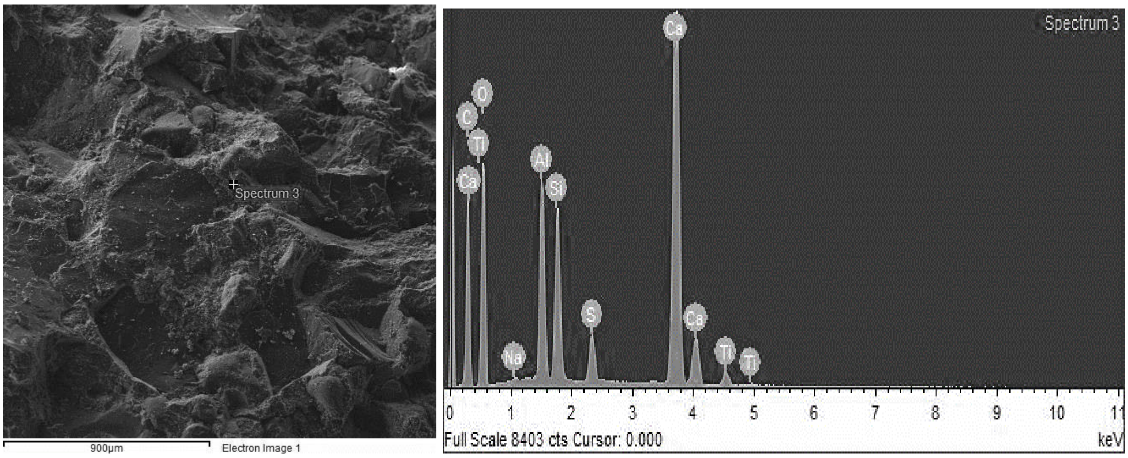
In Figure 2, an SEM micrograph of a terrazzo composite sample 1 is shown. It appears to be made of fairly edgy aggregates which implies some form of milling or grinding of the quartz aggregates in their preparation. Due to their generally increased surface areas, ground aggregates with edgy surfaces often provide a better adhesion with the matrices when compared to often roundish natural stone aggregates. The EDS spectrum of the particular phase depicted on the SEM micrograph (see the pointed region on Figure 2 (a)) shows that the point in question must be on a quartz particle due to the presence of Silicon and Oxygen. The identification of the Carbon atoms in the same region shows the presence of an organic additive and this might include organic plasticisers/superplasticisers often used to increase the followability of the concrete in the case where low water-cement ratios are preferred for stronger concrete (Mohammed *et al*, 2012, Rajamane and Ambily, 2012, Nanthagopalan *et al*, 2008).



(a) *(b)*

Figure 2. SEM microgram and EDS spectrum of a terrazzo composite (Sample 1)—a discrete phase

In Figure 3, the same Sample 1 is analysed but on a different phase. This is assumed to be a phase where the cementitious matrix is and its composition allude to the same assessment. The identification of calcium, silicone and oxygen reveal the presence of materials present in cement. In fact, a number of the elements in Figure 3 appear in the list of typical composition of cement clinkers shown in Table 1. Again, the identification of carbon atoms reveals the presence of organic plasticisers.



(a) *(b)*

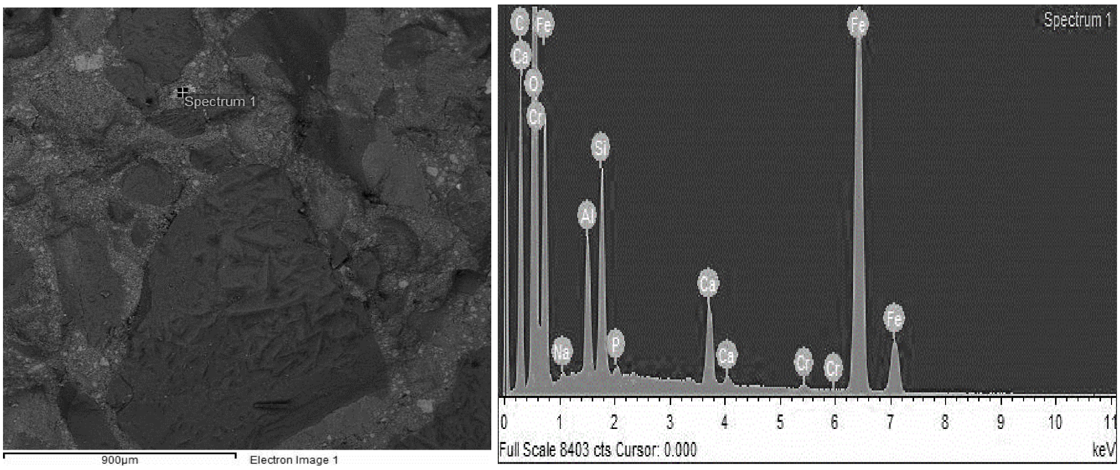
Figure 3. SEM microgram and EDS spectrum of a terrazzo composite (Sample 1)—a continuous phase

Table 1: Elemental composition of cement

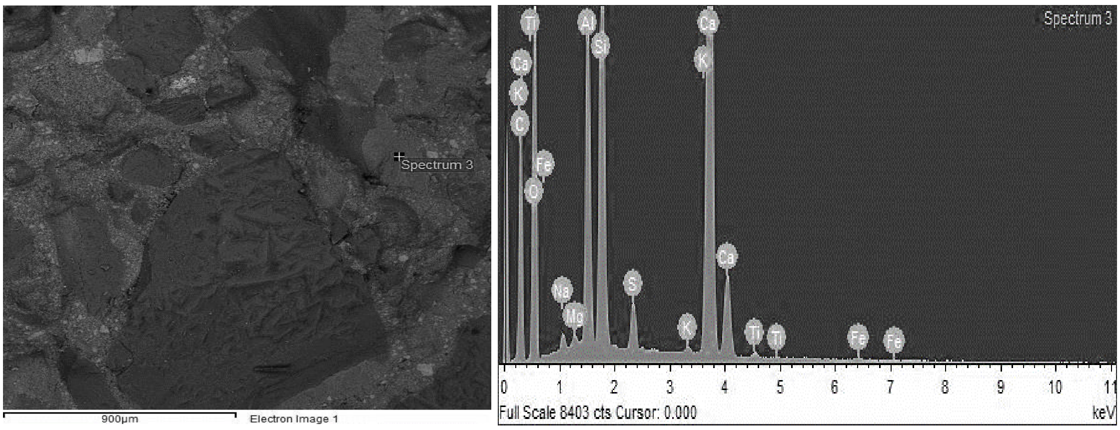
Clinker	*Cement Chemist Notation (CCN)*
Tricalcium silicate $(CaO)_3 \cdot SiO_2$	C_3S
Dicalcium silicate $(CaO)_2 \cdot SiO_2$	C_2S
Tricalcium aluminate $(CaO)_3 \cdot Al_2O_3$	C_3A
Tetracalcium aluminoferrite $(CaO)_4 \cdot Al_2O_3 \cdot Fe_2O_3$	C_4AF
Gypsum $CaSO_4 \cdot 2\ H_2O$	$C\bar{S}H_2$

For Sample 2, in Figure 4, the focus on quartz aggregates is skipped because the aggregates reveal the same results as those found in Figures 2 and 3 for similar reasons. Rather, focus is shifted to the two phases where there is a matrix. A closer look at the SEM micrograph in Figure 4 suggests that while there are two distinct phases; continuous and discrete, the continuous phase can be divided into sub-phases. These are sub-phases of markedly (1) white coloured dispersions within (2) light-greyish matrices. The EDS measurement was focused on the first sub-phase in Figure 4 (a) and on the second sub-phase in Figure 4 (c). On the first sub-phase, the EDS spectrum picks two elements, Chromium and Phosphorus (Figure 4 (b)), which do not appear in the second sub-phase, which is obviously purer cement matrix (Figure 4 (c) and 3 (d)) and have not been picked at all in the preceding spectrums in Figures 1and 2. The presence of such elements coupled with the fact that the region is distinctly physically different from what is clearly a cementitious matrix signal the presence of additives. The authors suspect the use of pozzolans which have been shown to improve the properties of concrete markedly (Dembovska *et al*, 2017, Naghizadeh and Ekolu, 2017).

For the engineered stone shown in Figure 5, the EDS measurements on aggregates reveal the same composition of quartz particles covered with carbon-based polymer as in previous cases. The only difference here is that the organic polymer is from polymer resins normally used in the making of engineered stones. Unlike in the case of terrazzo tiles, where the polymer is only used to plasticize concrete, the polymer itself becomes a matrix in this case. However, the EDS spectrum reveals presence of elements such as Sodium, Potassium, Aluminium and Calcium within the matrix. Additives are used in engineered stone composites for various reasons such as colour modification and improvement of translucency.

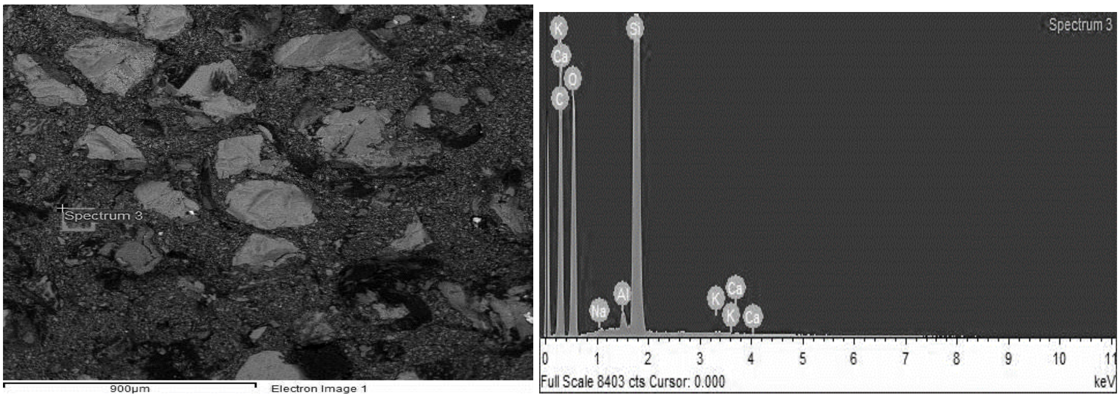


(a) *(b)*



(c) *(d)*

Figure 4. (a) and (b) SEM microgram and EDS spectrum of a terrazzo composite (Sample 2)—a continuous phase with an additive dispersion, (c) and (d) SEM microgram and EDS spectrum of a terrazzo composite (Sample 2)— a continuous phase.



(a) *(b)*

Figure 5: SEM microgram and EDS spectrum of an engineered stone composite (Sample 3)—a continuous but composite phase.

3.2. Aggregate packing within the composites

A composite of a terrazzo tile (Sample 1) is depicted in Figure 6. Due to the angular nature of its aggregates, the microgram shows a composite where aggregates and matrix are hardly distinguishable. However, the microgram reveals a compact mass which could indicate the use of compression, agitation and sometimes vacuum mechanisms in the production process of the composite to improve the packing of aggregates and reduce presence of voids.

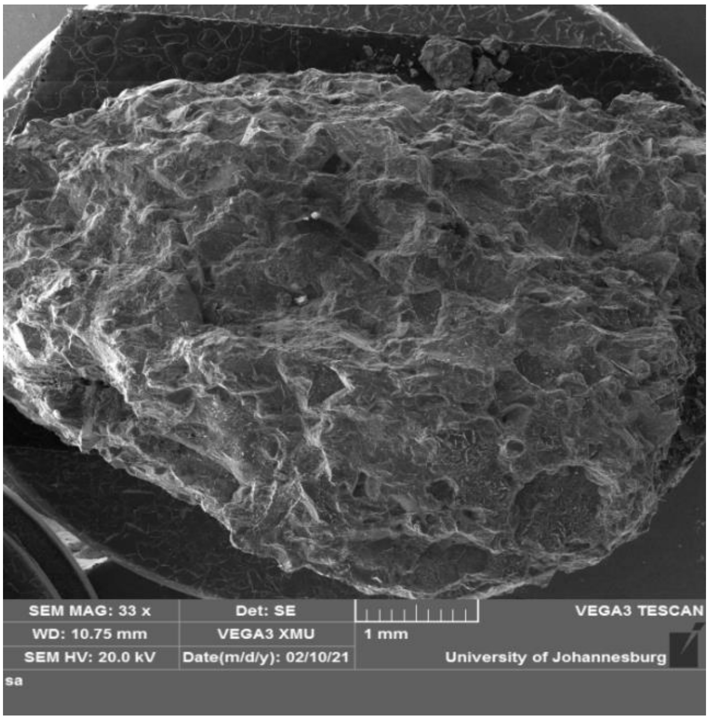


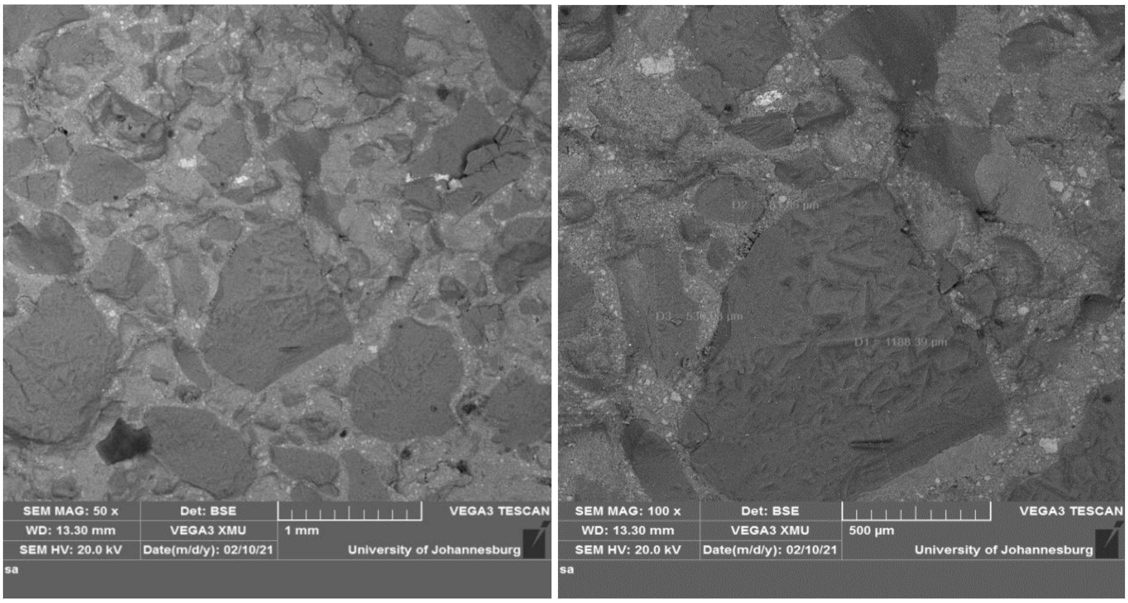
Figure 6: SEM microgram of a terrazzo composite (Sample 1)—aggregate packing

Interesting packing mechanisms are better revealed in micrograms on Figures 7 and 8. In Figure 6, aggregate packing in a terrazzo composite (Sample 2) is shown. It appears that in general, the choice of particle sizes used comes in three classes: Coarse (above 1000 µm), medium (500 µm -

1000 μm) and fines (100 μm -500 μm). In general, it appears that partilces below 100 μm were not prominent, if used at all. Some studies have found that such multisized aggregates packing are prefereable as smaller particle sized aggregates fill the interstices between particles of coarser sizes (Singh *et al*, 2020, Wenqiang *et al*, 2018). As has been suggested in theory, coarse particles seem to be randomly distributed in a matrix of fines or fines and medium particles as opposed to a theoritical ideal where fine particles are surrounded perfectly by coarse particles. When the terrazzo tiles were surveyed from a naked eye, it is clear that coarse particles have their size controlled through a sieve and they are uniformly distributed within a matrix of finer particles. It is important to note that this kind of packing, in which fine aggregates themselves become a matrix of coarse particles, does lead to better aesthetics in that when polished, shineness is given not only by coarse particles but by finer particles in between, providing little space for non-shining cement.

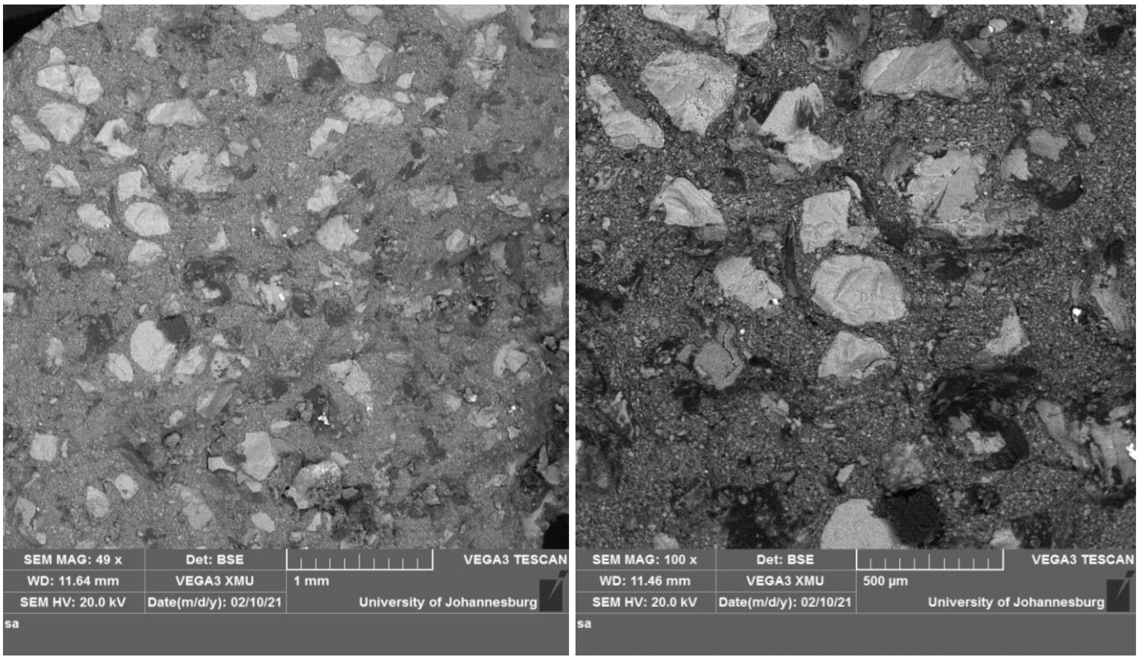
An even more interesting aggregate packing is revealed in the case of an engineered stone. In this stone, there are only two aggregate classes used: coarse particles in the neighbourhood of 0.2-04 mm and extremely fine aggregates in the neighbourhood of 0.01-0.04 mm. That makes for a unique packing. Again, in this case, the coarse particles are distributed within a matrix of fine particles all in a polymer resin. However, the sizes of the coarse and fine aggregates are extremely polarised. The results are huge phases occupied by fine particles in a resin matrix in which coarse particles are rather dispersed. This choice of packing mechanism, while it does not seem to be given any attention in literature at all, is probably effective. That is because the extremely fine particles leave minute interstices between themselves by virtue of them having such small sizes. They also leave extremely small interstices between themselves and the coarse particles, their extremely small size ensures that there is very little space between coarse particles that can be filled only by the resin. It is an effective packing mechanism which clearly needs no mathematical theories. This kind of pacing may explain why engineered stones can reach up to 95% of quartz stones and only 5% of the polymer resin by weight.

Considering the two packing arrangements in Figures 7 and 8, the first one is for a terrazzo composite which has its applications in tiles. The second one is for an engineered stone composite which has its applications in kitchen countertops. In the market, the price of engineered stone countertops can go up to ten times the price of the terrazzo tiles per square metre. So within the terrazzo composite, cost control is key. That is why the choice of matrix is a lower cost Portland cement and the size of aggregates is much bigger. For the engineered stone composite, the choice of matrix is an expensive polymer resin. The small particle sized fines used as fillers to suspend the coarse particles are often expensive. Getting them to that size of around 0.04 mm or less and the fact that quartz is extremely hard (comes fourth on the Mohs Hardness Scale) means a lot of grinding energy, the cost of which is transferred to the consumer against the background of superior physical and aesthetic properties.



(a) *(b)*

Figure 7: (a) SEM microgram of a terrazzo composite (Sample 2)—aggregate packing at lower resolution, (b) SEM microgram of a terrazzo composite (Sample 2)— aggregate packing at higher resolution



(a) *(b)*

Figure 8. (a) SEM microgram of an engineered stone composite (Sample 3)—aggregate packing at lower resolution, (b) SEM microgram of an engineered stone composite (Sample 3)— aggregate packing at higher resolution

4. Conclusions

Materials selection and aggregate packing of commercial grade terrazzo and engineered stone composites were analysed. Quartz is the obvious choice for hard surface materials, such as those investigated, due to its high hardness, scratch resistance and relative abundance and low-cost. Cement as a matrix is selected for low-cost and it is subsequently used in low-cost applications such as terrazzo tiles. However, for the high-end kitchen counter-tops, the selection of extremely tough polymer resins such as polyester is key. Ultra-high strength concrete in the case of cement-based composites is a priority where good properties and durability is necessary such as applications in terrazzo tiles. Therefore, the use of plasticisers has been detected in the cement matrix composites, probably due to the use of low water-cement ratio to improve properties.

Different choices of packing were observed in both terrazzo and engineered stone composites. In terrazzo, aggregates of different sizes such as coarse, medium and fine particles were detected. Such choices are made such that, to the extent possible, smaller particles fill interstices left by the next larger particles to reduce the content of the matrix. Absence of extremely fine aggregates may signal the need to reduce costs for such low-cost applications although there is a possible use of pozzolans mixed with the cement. On the other hand, the ingenious choice of aggregates is used in the engineered stone to maximum packing efficiency to the maximum achievable arrangement which, according to commercial outlets, leads up to 95% be weight of aggregates. However, the extremely fine aggregates surrounding coarser particles may come at a cost due to the energy needed to grind quartz into fines.

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Zambia Women Engineering Section (ZWES)

The Impact of COVID-19 Pandemic on Online Engineering Education: Female Students' Perspectives

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Abstract

The paper explored the impact of COVID-19 pandemic on online engineering education for female students at the Copperbelt University in Zambia. Prior to the pandemic, learning was primarily based on traditional methods of face-to-face lectures in a classroom. The sudden outbreak of the pandemic challenged the education system in Zambia and forced educators to transition to online environment. The survey was conducted for undergraduate and postgraduate female students to understand their perspectives on online engineering education amidst COVID19 pandemic. The statistical percentage distribution of the participants was used to assess the online learning outcomes. The findings of this study highlighted unstable internet access and connectivity, lack of practical lab experiments, unfavourable home study environment and finances as major setbacks to online learning. Home chores and childcare responsibilities were among other challenges students faced during online learning. The lack of pedagogical skills, and absence of traditional classroom socialisation were some of the other issues that affected mainly undergraduate students. Therefore, strategies are needed to build resilient education systems that will provide a positive learning environment to students for online engineering education, as this will certainly be useful even in subsequent years when the COVID-19 pandemic is not in effect.

Keywords: COVID-19; engineering education; online learning; female students.

1.0 Introduction

The novel coronavirus disease (COVID-19) was first discovered in Wuhan city of China in December 2020. The World Health Organisation (WHO) declared COVID-19 a 'pandemic' on 11th March 2020 owing to its rapid spread around the world (WHO, 2020; Kapasia, 2020). Governments worldwide have introduced measures to curb the spread of this highly contagious disease by imposing lockdown, social distancing, online learning, wearing of masks and restrictions on immigration (Gonzalez, *et al.*, 2020; Kapasia, *et al.*, 2020). The COVID-19

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pandemic outbreak forced many schools, colleges, and universities to close and switch to virtual learning platforms. The first two COVID-19 positive cases in Zambia were reported on 13th April 2020 which prompted the lockdown and closing of all schools. The country did not experience a sharp rise in COVID-19 and the government lifted some of the restrictions and schools reopened on 21st September 2020. The country continued to record low numbers of COVID-19 cases, however, towards the end of December 2020, a new variant was reported in Zambia which led to a sparked rise in the coronavirus cases and as of 16th February 2021, Zambia recorded 70,823 confirmed cases, 6,240 active cases, 63,609 recovered cases, and 974 deaths, standing at 86.5% recovery rate (MoH, 2021). The Zambian government have initiated several strategies to control the spread of the coronavirus disease such as online learning.

Online learning is the most feasible option due to its flexibility, accessibility, and learning pedagogy. Bourne (2005) suggested five metrics that drive studies into online education which include learning effectiveness, student satisfaction, faculty satisfaction, access, and cost effectiveness. The online environment helps students to learn anywhere and anytime thereby developing new skills leading to life-long learning. Schurgers, *et al*., (2009) observed that online learning creates interest in students, provides opportunities for innovative ways of achieving educational goals, and promotes student centered self-directed learning. Dhawan (2020) states that online learning environment serves as a panacea in the time of crisis because it is a relatively cheaper mode of learning in terms of the low cost of transportation, accommodation, and institution-based learning. Gonzalez, *et al*., (2020) reported a significant learning efficiency and performance through online learning strategies amidst the COVID-19 pandemic. On the contrary, Adnan and Anwar, (2020) found that online learning was ineffective in Pakistan because of lack of access to fast, affordable, and reliable internet connections particularly for students in rural communities. Further, Zhong, (2020) found that the lack of resources for academic institutions, poor internet connectivity and availability, lack of new technology and social marginalisation of students affected responsiveness of the institutions and students' capacity to participate in digital learning. Britt, (2006) observed that the real-time sharing of ideas, knowledge and information by the students was partially missing from the digital learning world as they could only communicate digitally and never saw fellow students in person. These mainstream observations call for heightened attention to protect and save students, academics, and the nation (Dhawan, 2020; Pace, *et al*., 2020; Karabulut-Ilgu, *et al*., 2020). Therefore, effective interventions are needed to create a positive study environment for students particularly in developing countries.

Despite advancement in technology and the transition to online environment amidst the COVID19 pandemic, engineering education has continued to lag behind in adopting to online methodologies. Bourne (2005) observed that online learning methods have not served some of the mainstay of engineering education such as laboratories, mathematical foundations, and design tools. The author notes that laboratories are conspicuously difficult to provide online learning because of the traditional requirement for direct operation of instruments as well as mathematics courses which require text-based discussions. Similarly, design tools have not been implemented as they often require computing power and graphics that are not readily accessible in distributed online environments. Further, Kapasia, *et al*., (2020) found that the online teaching-learning environment was discriminatory to poor and marginalised students. For example, women have traditionally been marginalised and disadvantaged, particularly, in developing countries due to religious and cultural beliefs (Sultana, 2010; Nyashanu, *et al*., 2020). This has contributed to low participation of women in engineering education, a field which is mostly dominated by men.

According to the UNESCO report, more than 11 million girls worldwide might not return to school due to education disruption caused by the COVID-19 pandemic. This adds to the 130 million girls who are already out of school before the pandemic (UNESCO, 2020). This threatens the effort made towards gender equality and puts girls at risk of adolescent pregnancy, early marriage, and violence. The education sector is struggling to find alternatives to deal with this challenging and dynamic situation. Therefore, strategies are needed to support and empower women in engineering education and bridge the gender gap.

The closure of educational institutions due to the sudden outbreak of COVID-19 pandemic challenged the education system in Zambia and globally, which forced educators to transition from traditional mode of learning to online environment. For a long time now, many universities and governments have talked about the need for online education or blended learning models where students' education is done online through student learning management system. However, schools have been slow to respond to this call. This transformation has resulted in the digital revolution in the higher education system through online learning, online examination, teleconferencing, digital open books, and interaction at virtual environments (Kapasia, *et al*., 2020; Kumar, 2020). Several studies on online engineering education methodologies have been conducted around the world, but effective interventions have not been thoroughly understood in most countries. This study aims to identify the learning environment, challenges of online engineering education amidst the COVID-19 pandemic for female students and suggests effective interventions for improved teaching-learning process.

2.0 Material and Methods

2.1 Data collection and procedure

In this study, an online survey technique using Google form was used to collect data on the female students' perspective on online engineering education amidst the COVID-19 pandemic. The participants were undergraduate and postgraduate female students studying at the Copperbelt University, Zambia. The online survey was conducted for the period between 20th January to 15th February 2021 for data collection. The questionnaire was structured to the assessment needs and the link was sent to students through WhatsApp and E-mail. The students were provided full consent before participation in the online survey. A total of 70 female students provided complete information on the survey.

2.2 Data analysis

The descriptive statistical analysis was conducted to understand the distribution of study participants and a percentage distribution was used to assess the online learning outcome, mode of learning, and strategy on engineering education decisions, and challenges amidst COVID-19 pandemic. All the analyses were carried out using Statistical Package for Social Science (SPSS).

3.0 Results and Discussions

The COVID-19 pandemic has forced many universities including Copperbelt University to recognise that the future is now. The Copperbelt University switched to online learning in April 2020 just like the rest of the world. This transition was difficult as the university lacked resources and infrastructure to respond to this sudden change which needed immediate attention. The first strategy by the institution was to organise training for faculty members on how to teach and share material through online platforms. The university also worked on its learning management system by integrating online platforms such as ZOOM and Moodle to enable both students and educators have better learning and teaching experience. This study is a follow up to the progress made by the Institution to assess undergraduate and postgraduate female students on online engineering education and suggests effective interventions to create a positive learning environment. The following were some of the main factors that influenced students' online learning:

3.1 Internet access and connectivity

Poor internet access and connectivity was found to be the major challenge of online learning for students at the Copperbelt University. This is because most students did not have access to high speed and reliable internet services. The situation was worse for students living in rural and remote communities in Zambia. Survey participants who had less challenges with internet access through smartphones, were equally unable to effectively use online learning because a significant amount of course content was not accessible on smartphones. Further, most students struggled with consistent access to electricity with which to power their devices during lockdown. Data access was also a challenge for many students as it proved to be costly. This sudden transition from traditional face-to-face learning to online learning caused a completely different learning experience for students. Efforts have been made by the Copperbelt University to engage network providers to provide cheap data for students, but this continues to be a challenge for most students due to economic challenges.

3.2 Experiments and fieldwork

The lack of practical lab experiments and field study was another major setback for online engineering students. Students could not conduct experiments which is part of their continuous assessment. Further, final year students delayed completing their projects and others had to switch to computer-based projects due to lack of access to laboratories during the lockdown. This affected the overall performance of students and others had to repeat the project course. Additionally, there were no industrial visits conducted to help students gain industrial practical experience.

3.3 Pedagogics

Lack of proper interaction with educators was found to be another challenge associated with online learning. Additionally, the online course contents are usually discussed with the relevant course educator via e-mail, and student reported long feedback time. However, after digital training by the Copperbelt University, students reported that some educators effectively used the online learning platforms by having more interactive classes and this helped them gain some new skills on how to use virtual platforms such as Zoom and Moodle. There is need to continue providing literacy training for educators on e-learning and assessing of students effective learning in online environments. Raju (2020) highlighted the need to adopt innovative teaching methods to improve learning outcomes and overcome anxieties and mental stress amidst the pandemic. Overall, most students indicated that the traditional classroom learning was more effective than online learning.

3.4 Resources

Lack of resources for poor and marginalised female students affected their preparedness and responsiveness to participate in online learning. Some students lacked technological skills to help them access online learning and others did not have specific devices such as computers/laptops or smartphones. Students were required to find resources to buy these devices and subscribe to internet providers for an effective and productive online program. A number of students indicated the need for a 24/7 help desk facility so as to help them access material at any time. Therefore, there is need to ensure adequate support from the Institution and the government of the Republic of Zambia for improved female students' performance in this digital world.

3.5 Socialisation and wellbeing

The traditional classroom socialisation was also found to be another missing aspect of online learning. The lack of classroom socialisation caused students not to do group projects on online learning mode. Students also experience family strain as some of their family members' health was at risk. Further, logistics difficulty of working from home and not being able to access certain necessities negatively affected their wellbeing. The social interaction activities are necessary for students' learning, growth, and mental health. Despite all these setbacks, some postgraduate female students indicated that they had more flexible working hours and more time available for self-care such as getting more sleep, doing exercises, and cooking better meals. Additionally, other students stated that they had more time to connect with family and friends remotely using technology.

3.6 Home chores and childcare responsibilities

Studying in a small space with home chores and childcare responsibilities was another main challenge for students especially during the lockdown when children could not go to school. This affected their progress as they needed to study and research while working and taking care of children at home. Postgraduates students particularly reported the difficulty in sending papers for publication, limited time for thesis writing and could not travel for conferences. Another challenge that the students encountered was the persistent gender bias that is still being experienced in our communities. Female students were given household chores and other responsibilities that male students were not. These household chores often interfered with their ability to participate in their online learning. Overall, both undergraduate and postgraduate female students indicated that they spent more time on home chores or childcare during the pandemic as compared to before the pandemic. This also had a positive side as both undergraduate and postgraduate female students indicated that the pandemic gave them an opportunity to spend quality time with their families leading to improved relationships with their siblings, children and spouses.

4.0 Conclusions

This systematic study assessed the impact of COVID-19 pandemic on online engineering education for female undergraduate and postgraduate students at the Copperbelt University and provided strategies for a positive learning environment. The findings of this study highlighted poor internet access and connectivity, lack of practical lab experiments, unfavourable home study environment and financial issues as main challenges of online engineering education. Home chores and childcare responsibilities were other challenges students faced during online learning. The lack pedagogical skills and traditional classroom socialisation were some other issues highlighted mainly by undergraduate students. Despite these challenges, other students indicated that online engineering education helped them to become more innovative, develop new technological skills, and provided a flexible mode of learning. Therefore, educational institutions must strive to continue working on strategies to overcome challenges of online engineering education and provide a positive learning environment for students, as this will certainly be useful even in subsequent years when the COVID-19 pandemic is not in effect.

5.0 Recommendations/Suggestions

This study suggests the following effective interventions to create a positive study environment for students:

1. There is need to improve the curriculum and design appropriate content for online lectures by educational institutions.

2. Universities need to continue innovating learning models as well as delivery methods and the infrastructure to support online delivery.

3. Institutions must continue providing digital literacy training for educators and assess students in a virtual learning environment.

4. Universities must provide psyco-social support to students and be sensitive to unique challenges women face. It is evident that women need to be supported and empowered during this unprecedented period.

5. There is need to change behaviours that limit female students' options and opportunities. Universities must advocate for female students to have the same opportunities to engage in learning as their male peers.

6. Strategies are needed to build a resilient education system to overcome the challenges of online engineering education amidst the COVID-19 pandemic.

7. Government support to educational institutions is crucial to help implement these effective interventions and achieve the desired results in online engineering education in this digital world.

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Smart mining through the application of unmanned aerial vehicles (UAV) and internet of things (IoT).

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Abstract

Smart mining involves the application of intelligent technologies that can greatly improve the quality of mining by enhancing high production, improved safety of operations, sustainable environmental management, and effective mine communication. The world is campaigning for sustainable utilization and exploitation of mineral resources by zero waste and zero mine accidents. Hence to realize this dream, the adoption of smart mining is becoming a priority. Smart mining entails that intelligent technologies are incorporated in the operations of the mines, these technologies include UAVs, robotics and artificial intelligence, Internet of Things (IoT) and different sensors.These technologies are at the helm of safer, faster and more effective collection of big data for better production planning, safety monitoring, transportation and fleet management, and real time monitoring of mining operations. The benefit of these technologies include effective decision making and more efficient response to safety emergencies of the mine. This study classifies UAV's based on wing type design, Altitude, Size and payload and weight and wingspan. Highlights are made of the different applications, advantages and challenges of UAVs and IoT in surface mine operations.

Keywords; Smart Mining, Safety Emergencies, Internet of Things, Unmanned Aerial Vehicles, Productivity, Environment, Intelligent Technologies.

1. Introduction

The COVID-19 pandemic is undoubtedly the defining global health crisis of our time, with governments and health services alike racing to slow the spread of the virus. Beyond the impact on global health, COVID-19 has shown its potential to create devastating social, economic and political challenges that will have lasting repercussions (World Economic Forum, 2020). The COVID-19 pandemic has affected the commodity markets in a variety of ways. Company operations have been affected through isolated outbreaks and government mandated shutdowns

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and the demand for many commodities remain low with a lower near-term demand on the horizon (Deloitte, 2021). To positively respond to this crisis, mining industries have to transform and adjust to smart mining operations through the application of Unmanned Aerial Vehicles (UAVs) and Internet of Things (IoT) technologies. Smart mining is hinged on sustainability and it will be defined as mining using latest technologies to enhance high efficiency in production, safety management, sustainable exploitation of mineral resources, effective communication, environmental monitoring and protection, real time monitoring of mining operations, cost reduction and timely decision making. The mining industry is venturing in the territory of digital and technological solutions with the primary purpose of achieving cost reduction and productivity enhancement based on optimal solutions, increase safety measures, and developing intelligent systems.

The rapid technological development and mature application of UAV and IoT technology makes it possible to obtain the operation progress of the mine, through the link connection relationship and the operation of the equipment from a high altitude where the presence of humans is difficult, impossible, or dangerous. Mostly mining companies are gathering data by the use of sensors and mobile telemetry to facilitate operational managers to improve operational efficiency. Data such as status becomes more convenient and feasible, which makes it possible to successfully apply the integrated command interaction platform based on the IoT, which is highly integrated and coordinated system for application in both open-pit mines and underground mines. The application of UAV and IoT technologies can establish a visual production interactive management and emergency command system which is of great significance to improve the production management level and emergency response capabilities of open-pit and underground mines, control production costs, and keep up with the forefront of high-tech development.

The focus of this research is the application of UAVS and IoT in the mining industry, specifically in the case of open pit mining. This paper will highlight the different types of UAVS and IoTs, their classification, application in the surface mines, advantages and disadvantages.

2. An Overview of UAVs and IoT

An Unmanned Aerial Vehicle (UAV)or drone is an aircraft without a human pilot on board as shown in Figure 1. It can be flown autonomously, where modern flight controllers can use software to mark GPS waypoints that the vehicle will fly to, and land or move to a set altitude. UAV’s can also be controlled manually with a hand-held radio control transmitter which controls the propellers. The Sticks on the controller allow movements in different directions and trim buttons allow the trim to be adjusted to balance the drone. Screens can also be used to receive live video footage from the on-board camera and to display sensor data. The on-board sensors can provide helpful settings such as:

- Auto altitude where the drone will move at a fixed altitude, and;
- GPS hold, where it will remain at a fixed GPS position.

Fig 1: Illustration of a DJI Phantom 4 Advanced+ /4k Camera Drone credit: Empire Rentals

This kind of autonomy is becoming increasingly common and contributes to much of the increased interest in civilian drone technologies that has been observed in recent years. UAVs are poised to become an integral part of smart mining and improve overall operational experience in the areas of drilling and blasting, haul road maintenance, monitoring fleet traffic, dispatching of equipment, supervising pit operations, monitoring pollution, accident investigation, fire-fighting, accessing hazardous and disaster areas, supporting first responder activities and increasing preparedness for emergencies.

Internet of THINGS (IoT) is a network of physical devices coming together from electronics, sensors, and software. The “THING” in IoT means everything and anything around us that includes machines, buildings, devices, animals, human beings, etc (N., 2019). IoT has a unique identification that is embedded relying on the RFID connections which does not need any human or human–computer intervention for its working Ashton, (2009). IoT devices are uniquely identifiable through embedded computing system and can be connected from anywhere through suitable information and communication technology, to achieve greater service and value. With the application of UAVs, IoT sensors embedded in mining equipment, buildings, slopes, specific targets can act as a primary source of data for UAVs in mining operations. Examples of IoT sensors used in the mining industry include the following: Wearables like smart helmets, wrist bands and smart vests, drill and blast precision sensors, fleet sensors and mobile apps as illustrated in the Figure 2. This helps mines respond to critical problems that are occurring in real-time.

Fig 2: Integration of UAVs and IoT in the mining industry, source (www.miningmagazine.com, 2019)

3. Classifications of UAV

There are different classifications of UAV's based on different parameters such as the goals and intended application. The selection of an appropriate type of UAV for mining purposes has to meet various requirements based on the specific expected services, the nature of the environment, and federal regulations for a particular region. Watts et al. (2012) classified the drones platforms based upon characteristics, such as size, flight endurance, and capabilities; resulting in MAVs (Micro or Miniature Air Vehicles), NAVs (Nano Air Vehicles), VTOL (Vertical Take-Off & Landing), LASE (Low Altitude, Short-Endurance), LASE Close, LALE (Low Altitude, Long Endurance), MALE (Medium Altitude, Long Endurance), and HALE (High Altitude, Long Endurance). Arjomandi et al. (2006) classified drones on the basis of weight, range and endurance, wing loading, maximum altitude, and engine type. They classified drones as super-heavy with weights more than 2000 kg, heavy with weights between 200 kg and 2000 kg, medium with weights between 50 kg and 200 kg, light/mini with weights between 5 kg and 50 kg, and finally micro drones with weights less than 5 kg. Gupta et al, (2013) classified drones as HALE, MALE, TUAV (medium range or tactical UAV), MUAV or Mini UAV, MAV, and NAV. Cavoukian (2012) categorized drones as three main types, namely, micro and mini-UAVs, tactical UAV's, and strategic UAV's. He divided the tactical UAV's into six subcategories: close range, short range, medium range, long range, endurance, and medium altitude long endurance

This review combines four classifications into one based on these four parameters which are wing type design, Altitude, Size and payload and weight and wingspan.

3.1 Wing type design

UAV's can also be categorized based on their design type of wings, and most UAV's can fall within one of four categories Alvarado et al, (2017):

- Fixed wing: Fixed wing UAV's vary significantly in size and design of wing spans. Fixed wings are more suitable for tasks involving long flights and variable payloads. As these UAVs glide in the air, they require less power to function and can endure longer periods and cover larger areas. However, because they cannot hover in a set point, fixed wings are less recommended for high precision data recording (e.g., ultra-high-definition imagery) (Alvarado et al., 2017). However, their build usually is integrated with fewer components than a multi-rotor UAV, hence being less prone to crashes or other accidents.

- Blimps are lighter than air and are characterised by low travelling speed, high maneuverability, low maintenance cost, low noise and vibration levels, low disturbance of the environment, capacity to hover and long flight endurance (Alvarado et al.), 2017).
- Flapping-wing: inspired by the movement of insect and bird wings; flight range and endurance are low compared to other UAV types.
- Rotary wing: also called vertical take-off and landing (VTOL), have lower cruising speeds. However, their high flight control and hovering capacity are characteristics which make them useful for scanning small areas with detail. Rotary wings are capable of withstanding high wind speeds and gust wind when compared to other types of UAV's. They require a greater amount of battery life to power multiple motors. Hence their flight endurance is lower than fixed wing UAV's Alvarado et al, (2017). They are preferred for research and civilian use due to their smaller footprint.

3.2 Altitude

Depending on the required flying altitudes, the UAV can be classified into high altitude platforms (HAPs) and low altitude platform (LAPs). HAPs can fly at altitudes above 17 km and are typically quasi-stationary (Zeng et al., 2016, Al-Hourani and Guvenc, 2020). They have long endurance and preferred for providing wide-scale wireless coverage for large geographic areas. A good example is a Blimps. LAPs, can fly at altitudes of tens of meters up to a few kilometers, can quickly move, and they are flexible (Al-Hourani and Guvenc, 2020). Compared to HAPs, the deployment of LAPs can be done more rapidly thus making them more appropriate for time-sensitive applications (e.g., emergency situations) and can be used for data collection from ground sensors. Moreover, LAPs can be readily recharged or replaced if needed.

3.3 Size and payload

Classification of UAV platforms can be made on capability or payload as shown in Table 1(Alvarado et al., 2017).

Table 1. Classification of UAVs according to their size (Alvarado et al., 2017).

Size	Characteristics	Payload	Operational constraint
Large (HALE)	Large operating range (~500 km); long flight time (up to 2 days); medium to high altitude (3–20 km).	~200 kg internally and ~900 kg in under-wing pods.	High set-up and running costs; requires ground station support, full aviation clearance, long runway for take-off and landing, a hangar for storage; altitude ceiling above commercial air traffic.
Medium (MALE)	Large operating range (~500 km); average flight time (~10 hours); average altitude (< 4 km).	~50 kg	Similar requirements to large UAVs but with reduced overall costs, requirements for take-off, landing and storage; and easier control.
Small/ Mini	Small operating range (< 10 km); low endurance (< 2 hrs); low altitude (<1 km).	Less than 30 kg (small); up to 5 kg (mini).	Line-of-sight flight only; mostly fixed wing; flown by flight planning software or by direct radio control. Only able to carry small payloads.
Micro/ Nano	Small operating range (<10 km); very short flight time (<1 hour); very low altitude (< 250 m)	Less than 5 kg.	Line-of-sight flight only; mostly fixed wing; increased instability with increasing wind speed. Only able to carry very small payloads.

3.4 Weight and wingspan

Hassanalian and Abdelkefi (2017) classified the drone range in size from vast fixed-wing unmanned air vehicle (UAV) to smart dust (SD), which consists of many tiny micro-electro-mechanical systems including sensors or robots. In Fig. 3, the spectrum of different types of drones is presented with a spread spectrum of drones from UAV class with maximum wing span of 61 m and weight of 15,000 kg to smart dust (SD) with minimum size of 1 mm and weight of 0.005 g. Between UAV and SD at both ends of the defined spectrum, there are various types of drones, which are called micro drones, such as micro unmanned air vehicle (μUAV), micro air vehicle (MAV), nano air vehicle (NAV), and pico air vehicle (PAV) (Hassanalian et al., 2016).

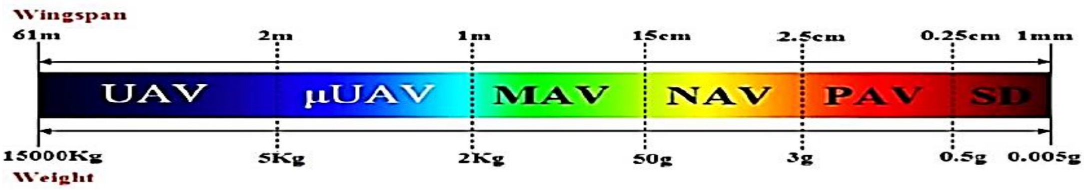

Figure 3. Classification of UAVs according to their weight and wingspan by Hassanalian and Abdelkefi (2017)

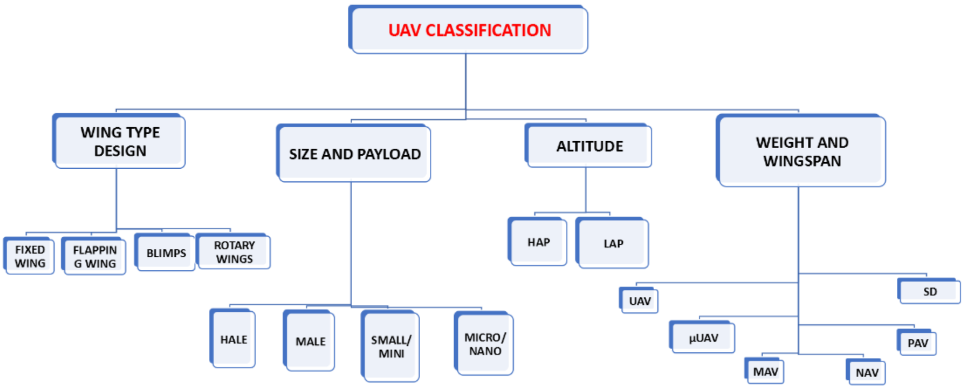

Fig 4: Summary of the classification of UAVs based on the author

4. Applications of Drones in surface Mining

UAV's have a variety of applications in the mining industry, especially when they are equipped with various sensors and cameras for conducting intelligence, surveillance, and reconnaissance missions. Additional applications include search and rescue missions, environmental protection, efficient replacement for ground-based survey methods, and many more. The applications of drones can be categorized in multiple ways depending on the type of missions, type of the flight zones (outdoor/indoor), and type of the environments (underwater/on the water/ground/air/space) (Hassanalian and Abdelkefi, 2017). These drones can provide a rapid overview around the target area without any danger. Drones equipped with infrared cameras can provide images even in the dark (Stuchlík et al., 2015). A summary is presented of some areas in the surface mine operations where drones or UAVs are applied below.

4.1 Geotechnical monitoring and failure analysis

Monitoring of open pit slopes is very critical for early detection of possible slope failure. The traditional method of slope monitoring conducted by humans through site observation near the slope spot can be hazardous. Human inspections also take longer to complete the investigation with some of the data collected being inaccurate because human view is limited. Advances in unmanned aerial vehicle (UAV) technology have resulted in a quick and safe tool for collecting detailed photographic records of the slope conditions. The use of UAV's is an alternative method to obtain quality picture, 3D-mapping and 3D model for inspection of slopes, and allows engineers to remotely, safely, and quickly perform a precise assessment of potential slope instabilities.

4.2 Drilling, Blasting and Fragmentation Analysis

Drilling and blasting accuracy is a common surface mining bottleneck because it accounts for a third of a mine's operating costs. UAV's are applied for precision drilling to eliminate drilling errors, which affect the blasting and fragmentation results. Data captured from drones allows the bench to be surveyed and photographed prior to the commencement of drilling. Prior to loading explosives, geo-referenced images of the drill pattern allow engineers to confirm that drill holes are in the correct location. Post blast images and video facilitate the analysis of rock fragmentation. This is a clear indication that drilling and blasting can benefit significantly from the application of drone technology.

4.3 Loading & Hauling

The load and haul operations in mining can be improved through aerial surveying techniques. Applications include:

- Measuring volumes excavated at the shovel/excavator face
- Monitoring bench elevations
- Creating digital terrain models of haul road networks.
- Real time dispatching of trucks to shovels
- Real time Assignment of tasks to operators

4.4 Strategic planning

Drones can be applied to monitor activities in the mines and topographical changes of the mining area, which can facilitate create guidelines for mine planning and safety (Xiang, Xia and Zhang, 2019). This is also useful for mine closure and reclamation planning and implementation. In addition, UAV's can be used for Mineral exploration, Road design and monitoring, Pit and leach pad design.

4.5 Stockpile Management

Reconciliation of ore and waste movement is a difficult task at most mine sites. Ground based survey techniques require surveyors to maneuver and navigate stockpiles while being subjected to weather and dust-related hazards. Aerial surveying with drones removes the person from the work area and allows the surveying to take place without interrupting the mining process. Aerial surveys can take place on a regular schedule, allowing for accurate updates on the mining company's valuable asset (UKU Tech Limited, n.d.).

4.6 Mine Safety and risk management

The UAVs can be used for damage assessment, emergency accident response, incident monitoring, regular safety site survey, security and asset protection, incident data capture and illegal mining monitoring.

4.7 Environmental monitoring

By acquiring regular aerial survey data, the mining operation can ensure environmental compliance to local regulations (UKU Tech Limited, n.d.). UAV'S makes it possible to conduct tailings management and assessment, and quickly monitor and detect land use and vegetation encroachment . In addition, water pollution and leakage can be detected and soil pollution can be identified.

4.8 Equipment and Infrastructure Inspections

The mine infrastructure can quickly be inspected where previously inspections had to be carried out by people in often hazardous conditions. By using drones to capture video and images, regular inspections can be carried out safely and cheaply. Mining companies are required to inspect:

- Tailings dams and erosion
- Watershed, drainage and hydrology conditions
- Conveyor belts
- Bridges
- Roads
- Towers
- Pipeline inspection
- Trolley lines

Significant cost savings will be achieved with uninterrupted operation of the equipment, and safety is improved through no human contact with the asset. Equipment inspections using UAV's are vital for maintenance and productivity reports as inspections are easily facilitated with the IoT sensors embedded in the equipment.

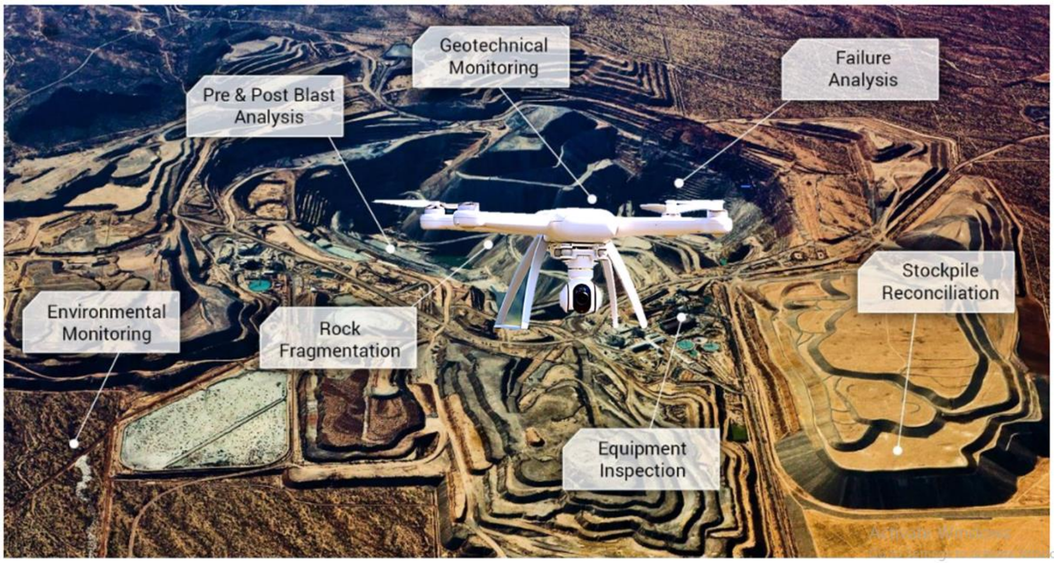

Fig5: Different applications of UAV in surface mines modified Illustration credit: (UKU Tech Limited, n.d.) Airobotics

5. Discussion

The application of UAVs in the mining industry offers a lot of advantages since they are excellent for taking high-quality aerial photographs and video, and collecting vast amounts of imaging data. These high-resolution images can be used to create 3-D maps and interactive 3-D models, which have many beneficial uses. Since unmanned aerial vehicles use the Global Positioning System

(GPS), they can be programmed and maneuvered accurately to precise locations. The precision of UAV's saves mines both time and cost. UAV's are able to fly lower and, in more directions, allowing them to easily navigate traditionally hard-to-access areas (Ohio University, 2019). While there are numerous pros to using drones, there are also several perceived challenges to their deployment. These concerns are important to consider, particularly given the wide range of circumstances in which drones can be used. Safety is a primary concern when dealing with unmanned aerial vehicles. In surface mines, weather conditions present a challenge by inducing deviations in drone's predesignated paths compared to underground mines. In some cases, weather conditions can be damaging to the drones, leading to failure in their missions. To avoid mid-air collisions, UAVs must be programmed with "sense and avoid" capabilities that match those of manned aircraft. This means that drones must be able to detect a potential collision and maneuver to safety (Ohio University, 2019). In the event of system failures, falling drones are another serious danger for the mines. UAVs can collect data and images without drawing attention, hence might jeopardise the public privacy. Since the widespread use of unmanned aerial vehicles is relatively new, legislation is still catching up especially in developing countries. There is a lack of a standard classification system for UAV's It is therefore imperative to have a common understanding of the parameters which would define a UAV in order to have a uniform classification system.

6. Conclusion

To address the fundamental challenges due to the COVID-19 pandemic in the mining industry, the application and adoption of UAV and IoT technologies is a step in the right direction. UAV technology is attractive in surface mining due to its efficiency and low cost compared to the traditional monitoring methods. Different UAV classifications exist and four classification characteristics have been adopted in this research including wing type design, altitude, size, payload and capacity, and wingspan. Fixed-wing and rotary-wings drones are the most commonly used drones in the mining industry, including both research and commercial applications. The current study has also discussed drone applications through various stages of the mining life cycle including unit operations, processing and closure. Despite a few challenges such as adverse weather conditions which can be damaging to the UAV's and possible lead to failure in the planned mission, there are more benefits in the application of UAV's and IoT technologies in the mining industry.

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