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The Development Bank of Southern Africa's (DBSA) African Journal of Infrastructure Development aims to serve as a preeminent platform for scholarly discourse, presenting cutting-edge research and analytical insights into the complexities of infrastructure development in the African context. It aspires to bridge the gap between theory and practice, fostering a multidisciplinary dialogue that spans economics, urban planning, engineering, environmental science, finance, and public policy.

This scholarly publication is dedicated to examining the multifaceted nature of infrastructure projects from conceptualization to implementation, including the evaluation of economic impacts, the exploration of innovative financing mechanisms, and the assessment of sustainability and governance practices. It seeks to discuss and expand the challenges and opportunities inherent in developing resilient infrastructure that can withstand socio-economic and environmental pressures while propelling inclusive growth and regional integration.

The journal's scope encompasses both macro and micro perspectives, inviting contributions that analyze national frameworks, regional cooperation models, and case studies of specific infrastructure projects. By providing a forum for the exchange of ideas among academics, practitioners, policymakers, and international development agencies, the journal endeavors to influence the discourse on infrastructure development policies and contribute to the achievement of sustainable development goals in the African continent. With a commitment to rigor and relevance, the DBSA's African Journal of Infrastructure Development strives to impact not only the academic community but also practical applications in the field. It encourages submissions that employ diverse methodologies from quantitative studies and policy analyses to qualitative research and comparative reviews, all aimed at enriching understanding and guiding effective action in Africa's infrastructure sector.

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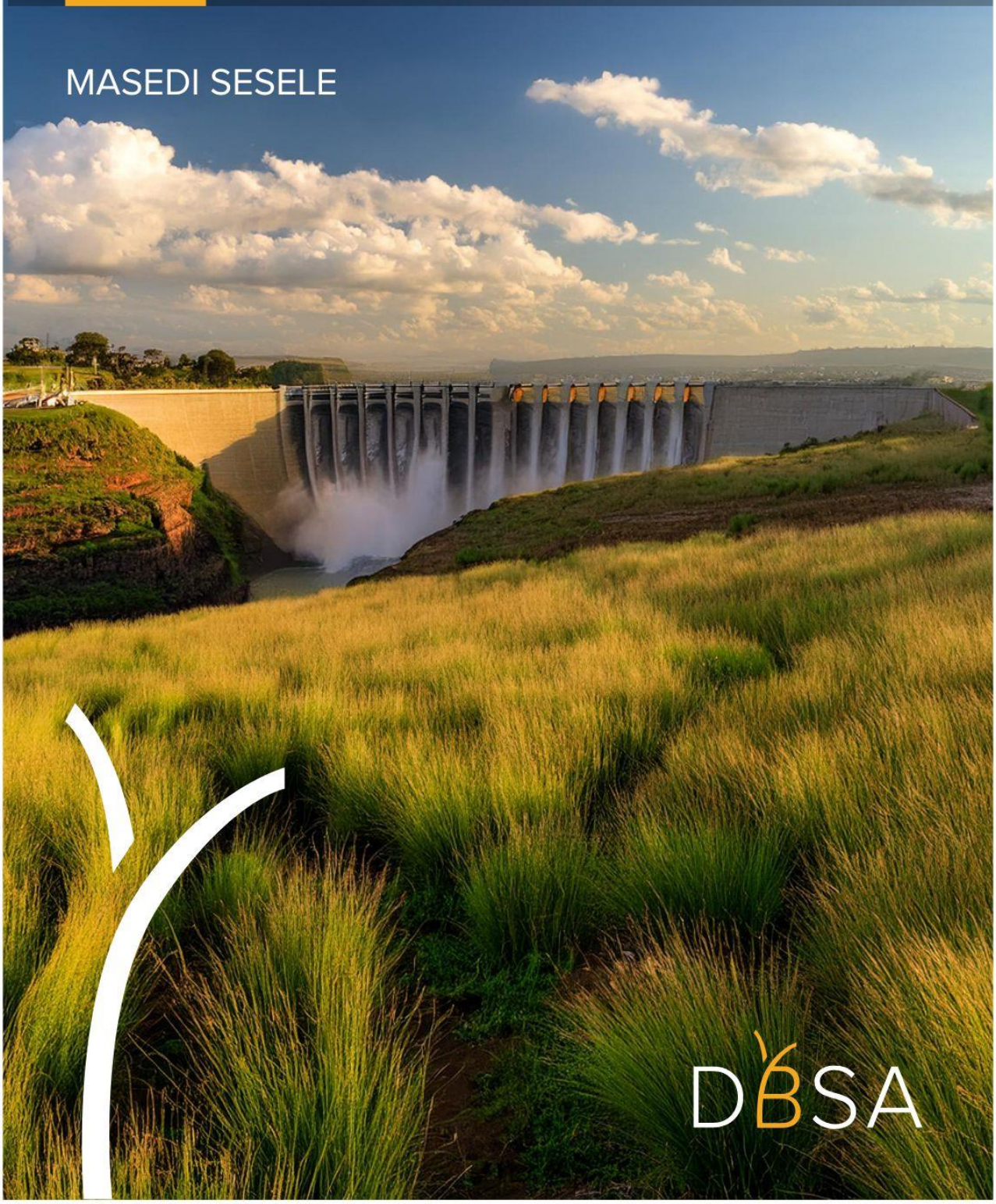

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THE ROLE OF DEVELOPMENT FINANCE INSTITUTIONS IN FRAGILE ECONOMIES

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ABSTRACT

This research explores how development finance institutions (DFIs) can effectively operate in fragile economies and identifies investment sectors with the highest growth potential. It examines the roles and strategies DFIs should adopt, the challenges they face, and offers policy recommendations to enhance development finance in such environments. The study utilizes a systematic literature review on fragile states and DFIs' involvement, supplemented by a case study to highlight successful economic interventions. It begins by analysing the concept of state fragility, focusing on economic, political, and social factors necessary for recovery and growth. Key findings highlight that DFIs play crucial roles in fragile economies by supporting pioneering businesses, offering patient, adaptable, and risk-tolerant financing, and addressing gender disparities. Additionally, DFIs contribute through trade finance, advisory services to both firms and governments, and infrastructure development. These actions position DFIs as vital catalysts for economic stability, private sector growth, and long-term resilience in fragile contexts. However, a notable limitation of the research was the scarcity of available data and low engagement from key informants, which restricted the case study analysis to a single country. Despite this, the research offers valuable, practical recommendations for development finance practitioners and policymakers. It emphasizes actionable strategies that can increase the effectiveness and developmental impact of DFIs in fragile economies. Ultimately, the study underscores the importance of targeted investment in fragile states, arguing that such interventions are essential for reducing fragility and fostering sustainable economic progress, benefiting both the nations involved and their populations in the long term.

Keywords: Fragile States, Development Finance, Economic Growth, Data Availability, Investment

INTRODUCTION

Fragility and conflicts prevent countries from achieving sustainable development goals. Despite efforts to elevate global poverty over the past few decades, there is a growing number of the world's population which continues to live in extreme poverty. Of those living in extreme poverty, 76,5 percent is in fragile economies where almost one-quarter of the world's population lives (OECD, 2020). Fragile states differ from each other but tend to share common features such as a divided society with opposing views and no shared identity. These states have inadequate government capacity and lack the capability to perform basic functions such as taxation, and providing security, the rule of law and economic infrastructure. These states also lack legitimacy with many of their own citizens and have few formal enterprises. The workforce cannot therefore reap the economies of scale and specialization which results in an unproductive and impoverished population (Collier, et al., 2019). Development finance institutions (DFIs) have a mandate to achieve development impact including in the world's most fragile states to bring job and economic opportunities to societies that need them most. However, investing in these states is complex with significantly higher associated risks and costs. Unlike commercial lenders, DFIs are more tolerant of higher risks as they often pool financing and operate under explicit development mandates. They can also leverage their capacity to use public funding to de-risk investments while using their expertise, networks, and influence to mobilise collaborative approaches to project co-investment. Therefore, the objective of this study is to assess key roles and approaches required by DFIs when investing in fragile economies.

BACKGROUND

The term fragile economies can describe a heterogeneous group of countries with problems of governance, security, and development. Initially, the fragile state agenda focused on conflict and post-conflict countries (Maier, 2010). But this has since been broadened to cover aspects of security, economic and social development as well as political representation and governance (Maier, 2010). African scholars such as Ncube and Jones (2013) have found fragility difficult to define due to the term being fluid and partly because it represents a continuum, with states moving in and out of it. This depends on a nation's ability to respond to internal and external shocks. The main attributes of fragility, however, include the inability to deliver essential services due to weak capacity and institutions, poor policies, and political instability.

The Organisation for Economic Co-operation and Development (OECD) (2020) described fragility as the combination of exposure to risk and insufficient coping capacity of the state, systems, and/or communities to manage, absorb, or mitigate those risks. It further stated that fragility can lead to negative outcomes, including violence, poverty, inequality, displacement, and environmental and political degradation (OECD, 2020). The African Development Bank (AfDB) defines fragility as a condition of elevated risk of institutional breakdown, societal collapse, or violent conflict. Furthermore, fragility is an imbalance between the strains and challenges (internal and external) a state and society face and their ability to manage them (AfDB, 2022). The AfDB shifts the concept paradigm from "fragile states" to "fragile situations" to reflect that fragility can manifest at the local, national, or regional level in any country regardless of its political or socio-economic standing (AfDB, 2022). The DBSA defines fragility as countries or situations with unique development challenges that are exposed to risk arising

from fragility and conflict where institutions of governance and communities cannot manage or mitigate those risks (DBSA, 2021). Fragility contexts can negatively impact development outcomes, including violence, poverty, inequality, displacement, and environmental and political degradation (DBSA, 2021).

Fragility also includes vulnerability to climate change and natural disasters (Azour & Selassie, 2023). Economic growth theory has shown that the accumulation of physical and human capital, as well as technical progress, may have a positive impact on growth (Maier, 2010). Fragile states have, however, accumulated less capital than others and have lower rates of technological progress, which hinders their growth potential (Maier, 2010). The issues facing fragile economies reinforce each other as the society is divided into two opposing groups where one group tends to believe that the state is captured by the other and, therefore, undermines the legitimacy of the state (Collier, Gregory, & Ragoussis, 2019). Because of this lack of legitimacy, the state cannot rely on members of society for compliance or community engagement, resulting in the state failing. The lack of legitimacy and inadequate state functions results in lack of business confidence and employment opportunities. This leaves fragile economies exposed to shocks which the state cannot cushion and as such the frequency and severity of adverse shocks keep derailing attempts to escape from fragility (Collier, et al., 2019).

The study by McKechnie, et al. (2018) states that fragile economies are dominated by the agriculture sector, as on average they have a higher proportion of employment within this sector. The process of moving labour out of lower-productivity agriculture and into high-productivities is crucial for structural change (McKechnie, Lightner, & Velde, 2018). The current state of development finance in fragile economies has shown that although overseas development assistance (ODA) remains a critical source of financing for governments in fragile states, the desired level of economic growth remains unachieved (MENA-OECD, 2018). ODA from Western funders is larger than foreign direct investment (FDI) in these states but not all ODA is intended for long-term development purposes as some is allocated for humanitarian needs which do not align with Africa's agenda. ODA accounts for 28 percent of financial flows in fragile states while FDI accounts for 22 percent (MENA-OECD, 2018). The record of DFIs in fragile economies has received criticism as they have been accused of adopting risk-averse investment strategies and transactional approaches to investment deals, putting financial returns above development impact (Collier, et al., 2021). DFIs have invested in well-off markets and safer sectors, thus sourcing very few new opportunities in fragile markets.

Fragile economies are characterised by environments with a heightened exposure to investors' risk combined with a low government capacity to mitigate, manage, or absorb these risks (Abel, Hammond, Hyslop, Lahidji, & Mandrella, 2016). As such, the business climates in these economies are not enabling. The Doing Business Report (World Bank, 2019), which compares business regulation for domestic firms in 190 economies shows that fragile economies are among the lowest ranked countries in the world with Somalia, Yemen, South Sudan, the Democratic Republic of Congo, and the Central African Republic as examples. Table 1 shows that Libya is ranked 186 and scores poorly across all indicators, as since the 2014 relapse in conflict, the country has lacked basic regulations and institutional mechanisms that support the creation and operation of private firms. Iraq also ranks 171 and has performed poorly on indicators such as getting credit and trading across borders. Fragility in some nations such as Iraq, can also be attributed to the impact of the United States invasion of the country

in 2003 which resulted in the disbanding and dismantling of the Iraqi military and bureaucracy. This exacerbated economic stagnation, terrorism, criminality, and crumbling infrastructure issues which are still present today (Flibbert, 2013).

Table 1: 2019 Doing business ranking globally

Economy	Global rank	Starting a business	Dealing with constructio	Getting electricity	Registering property	Getting credit	Protecting minority investors	Paying taxes	Trading across	Enforcing contract	Resolving insolvency
Jordan	104	106	139	62	72	134	125	95	74	108	150
West Bank and Gaza	116	171	157	85	84	22	161	107	54	123	168
Egypt, Arab Rep	120	109	68	96	125	60	72	159	171	160	101
Lebanon	142	146	170	124	105	124	140	113	150	135	151
Iraq	171	155	103	126	113	186	125	129	181	143	168
Libya	186	160	186	136	187	186	185	128	128	141	168

Source: MENA-OECD (2018) and World Bank (2019)

Studies such as Velde (2011) estimated the aggregate impact of DFIs on investment (especially during financial crises and in post-conflict periods) and the ability of DFIs to improve energy efficiency. The results from the study showed that a one percentage point increase in DFI as a percentage of gross domestic product would lead to a 0.8 percentage point change in the investment to GDP ratio. Hence, DFIs could be seen as a useful tool to promote investment and growth in poor countries. Comparable results were found in studies like Schreiner & Jacob Yaron (2001) and Humphrey & Michaelowa (2019).

RESEARCH METHODOLOGY AND METHOD

To address the objectives of the study, the methodology followed two approaches. Firstly, a systematic review of existing literature regarding fragile economies and the role and involvement of DFIs in these economies. The systematic literature review approach is preferred as it provides a comprehensive overview of literature related to a research question and synthesizes previous work to strengthen a particular topic's foundation of knowledge, while adhering to the concepts of transparency and bias reduction (Williams, Jr., et al., 2021). Secondly, a case study was conducted to identify evidence of economic success in a fragile state using the Liberian construction sector. The use of a qualitative case study is ideal for the purpose of this study, as unpacking the dynamics of successful intervention of development finance initiatives in a fragile state provides lessons learnt that can be replicated in other fragile settings. It also provides practical solutions which have a proven record of success in a fragile state. Through a desktop search of successful development finance interventions in fragile states, a number of projects were identified (in countries such as Afghanistan and Mauritius), and questionnaires were sent to key informants in each project. The key informant in Liberia was the only respondent, hence it has been the only included case study in this analysis.

RESEARCH RESULTS AND DISCUSSION

The research results and discussion section are divided into two subsections. The first is the systematic literature review section which is divided into subsections and documents both local and international literature on fragility and the distinct roles and challenges facing development finance institutions. The second is the case study analysis section of the construction sector in Liberia which documents a successful intervention of development finance in a fragile country.

Systematic Literature Review

Fragility and inequality

The African Development Bank strategy for addressing fragility and building resilience in Africa highlighted horizontal inequalities, social exclusion and gender inequalities as key drivers of fragility that will need to be explicitly addressed in operational areas (AfDB, 2022). Social drivers of fragility can be pushed by the demand of individuals or groups in a society for inclusion and access to services, resources, and opportunities that if not met leads to grievances, social tensions, rebelliousness, and violence (AfDB, 2022). Gender inequality is another important driver of fragility, as conflict and fragility affect women, men, girls, and boys differently. Women and children have been historically marginalised, and conflict can further cause greater gender inequalities and increase the vulnerability of women and children (AfDB, 2022).

In their study, Koch (2008) highlighted how women and girls are often disproportionately affected by conflict as opposed to men and boys. In conflict affected states, girls' enrolment in primary and secondary school has been found to drop drastically as they are forced to stay home and assist with household duties (Koch, 2008). The enrolment of boys in school has in some states also been negatively affected as they are forced to drop-out of school and take part in the violence. There is also inequality regarding healthcare in fragile states as wounded men compete with women who require health services such as giving birth (Koch, 2008). Women and girls are also often tasked with the burden of taking care of the wounded and the elderly in their households and the society at large which puts more strain to their own well-being (Koch, 2008).

In terms of employment, there is mixed evidence regarding how country level fragility and conflict affect people. It is, however, evident that with men having been involved in the conflict, most households will be led by women, who will have the sole responsibility of providing financially for their households. In some literature, this has driven women into income generating long hours work in the informal sector such as farming (Quek, 2019; ILO, 2003; Nelson-Núñez, 2019). However, in some instances, women accept work in formal sectors which were left by men when taking part in the conflict (Koch, 2008). The violence experienced by people is also different in fragile states as men are likely to be wounded and die in the fighting, but for women, gender-based violence increases substantially. In the absence of law and order, the trafficking of women and sexual exploitation increases drastically. Women are unable to arm and protect themselves and lack the mobility to flee the violence. Men may also suffer from gender-based violence but because of the stigma involved, the degree of it is unknown.

Escaping Fragility

Structural changes

The analysis of the economic growth theory models has shown that in order to foster growth in fragile states, capital and labour productivity are highly essential (Solow, 1956). Escaping the poverty trap and fragility will therefore involve social, political, and economic stability within these states. That in turn will cause structural changes and the efficient use of factors of production – shifting from lower to higher production activities. Wen (2016) provided an analysis of China's rapid rise from a backward agrarian society to an industrial powerhouse in 35 years. The study showed how China's shift from rural agriculture and informal services towards growth driven industrial sectors has resulted in its rapid economic growth. The structural shift from low to high productivity activities will result in underemployment and unproductive jobs being replaced by more productive jobs in the formal private sector. This will result in more jobs being created and the overall national income of the country increasing (Collier, et al., 2021). Household income can increase and as such they can engage in spending on education, healthcare, and savings which according to the Solow growth theory can foster growth (Solow, 1956).

The shift to industrialise an economy also involves the support of critical infrastructure such as roads, power generators and financial services. Fragile economies also have a limited export base when excluding natural resources and as such the firms' growth in these states is limited. The structural change will allow for the development of an export base for fragile economies which will increase firm-level growth and create trading channels with the rest of the world (Collier, et al., 2021). With increased firms and an increased export base, governments in fragile states will have an opportunity to broaden their tax base and increase their tax revenue to enable them to provide basic public goods and services and improve infrastructure. These structural changes are difficult to attain and require the government to create an enabling environment where the private sector can thrive (Noman & Stiglitz, 2015). The structural change process is driven by the private sector as firms have a competitive incentive to improve efficiencies and productivity. Without productivity growth and structural change, fragile economies have become stuck in low development equilibria with stagnating or falling growth rates (Noman & Stiglitz, 2015)

Pioneering firms

The environment in fragile economies is not conducive for economic activity to take place, as such pioneering firms are essential as they take the first investment steps (Covin, et al., 2000). Market pioneering is a commonly recognized form of corporate entrepreneurship where a firm is first to offer a distinctively new product, introduce a new process or enter and create a new market in fragile economies (Covin, et al., 2000). Pioneer firms are regarded as "first movers" in fragile economies and have the advantage of accessing unexploited natural resources, using low-cost labour, provide basic services and have open entry to the market with little competition (Collier, et al., 2019). By embarking in investment in uncharted fragile territory, pioneering firms will provide knowledge regarding the market structure and how to navigate it. Pioneering firms also provide jobs and training to the members of the society, support infrastructure and stimulate the local market. The risk of pioneer firms going under is high as they have no prior knowledge of the local market conditions and as such will experience the necessary trial and error phases.

The start-up cost of establishing these firms in these economies is also extremely high. The firms have to consider developing non-existent infrastructure, navigating the regulatory environment, labour training and the possibility of failure due to unprofitability, conflict, or political uncertainty (Collier, et al., 2021). A perfect example is the Southern Sudan Beverages Ltd which was a pioneering investment in South Sudan owned by SABMiller Group. The firm was established in 2009 and later went out of business in 2016 (Brewver, 2009). The pioneering firm which was at the time the pride and joy of South Sudan was unable to survive the 20-month civil war which killed more than 10 000 people and further forced two million from their homes and left 4,6 million people with severe food insecurity (Jones, 2015). The South Sudan brewery experienced shortages of fuel, raw material, and foreign currency. It lacked financing and lacked domestic inputs as the banking sector in South Sudan was underdeveloped and the local agricultural and industrial development was weak. This resulted in the majority of the inputs such as maize, malt, bottles and bottle tops being imported from neighbouring countries (Jones, 2015).

State building

The OECD (2008) has defined state building as the endogenous process to enhance capacity, institutions and legitimacy of the state driven by state-society relations and this involves the process of states functioning more effectively. The OECD (2008) has prioritised state-building as the central objective of international partnership in fragile situations and in countries emerging from conflict and state building therefore remains an essential aspect in escaping fragility (OECD, 2008). The process of state building involves reciprocal relations between a state that delivers services for its citizens and social and political groups that constructively engage with their state. The process also involves legitimizing the state by amongst other aspects, ensuring its ability to provide services effectively and equitably to its people. As such legitimacy is both a means and an end for successful state building (OECD, 2008). The development of administrative capacity within a state is also key for state building as a state cannot exist without administrative structures such as a functioning civil service and a public economic management system.

This also involves the ability of the state to raise funds through taxation which ensures that the state has a stake in its citizens' prosperity and the citizens can hold the state accountable for its performance or management of their taxes. In the context of a fragile state, the establishment of a resilient state is of the utmost importance as a resilient state must be able to effectively deliver functions that match the expectations of its society (OECD, 2008). Managing the process of change and external and internal shocks associated with it remains important as failure to do so may generate violence and fragility. Failure of a state to be inclusive of all societal or political groups can also lead to the excluded groups challenging the state which can result in violence. In state building, it is therefore important for the state to engage and negotiate with all groups especially marginalized ones such as women and people with disabilities, to avoid undermining state building efforts overall (OECD, 2008).

The key role of DFIs in fragile economies

Supporting Pioneering firms

One role DFIs can play in fragile states is by expanding their toolkit and providing support to pioneering firms. This is a mutually beneficial activity as in order for DFIs to identify sectors with high growth potential in fragile economies, supporting the entrance of pioneering firms in different sectors of a fragile economy will provide information regarding the risk and benefit within such sectors through experiences that they have faced (IFC, 2017). The generated information can reduce uncertainty and allow DFIs to have more information on which sector to invest in. There are several channels through which DFIs can support pioneering firms and the private sector as a whole. One of the channels is through subsidy mechanisms. Traditionally, subsidies would be provided by the government, however, governments in fragile states lack the fiscal, administrative, and financial capacity to do so (IFC, 2017). Therefore, there is a role for DFIs to play by providing subsidies to pioneering firms as part of their financing role (IFC, 2017). DFIs can provide subsidies through blended financing mechanisms where they combine commercial financing terms with subsidies linked to specific costs, benefits, and risks. Blended concessional finance is a significant tool which DFIs can use to increase finance for private sector projects to help address Sustainable Development Goals and mobilise private capital (IFC, 2017). Between 2014-2016, DFIs had financed a total project value of more than USD 15 billion by various blended finance solutions. Figure 1 shows the various financial products used by DFIs.

Senior concessional loans and equity are more prevalent but there was also use of risk sharing facilities, subordinated loans, and grants. The sectors that were most targeted by the concessional resources were infrastructure, banking, and agriculture, while climate change was the most prevalent theme within these sectors (IFC, 2017). Figure 2 shows the rationale for using blended finance as identified by DFIs. Most projects were based on pioneering technology or creating markets and projects reaching underserved beneficiaries. DFIs can also play a role in actively seeking out such firms that are willing to participate in pioneering new markets in fragile states and support them through such subsidies. However, the design of the subsidy allocation mechanism should support market creation and not give an advantage to the recipient that goes beyond the first mover/pioneer costs that it bears (IFC, 2017). DFIs also have a role to play in providing technical assistance and capacity building to firms in fragile economies through providing subsidized advisory services that support job training, market assessment and costly activities which pioneering firms need to undertake. DFIs can also go beyond firms and provide technical and capacity building support to governments in fragile states to help market creation which will in turn decrease the cost faced by firms entering these markets (IFC, 2017).

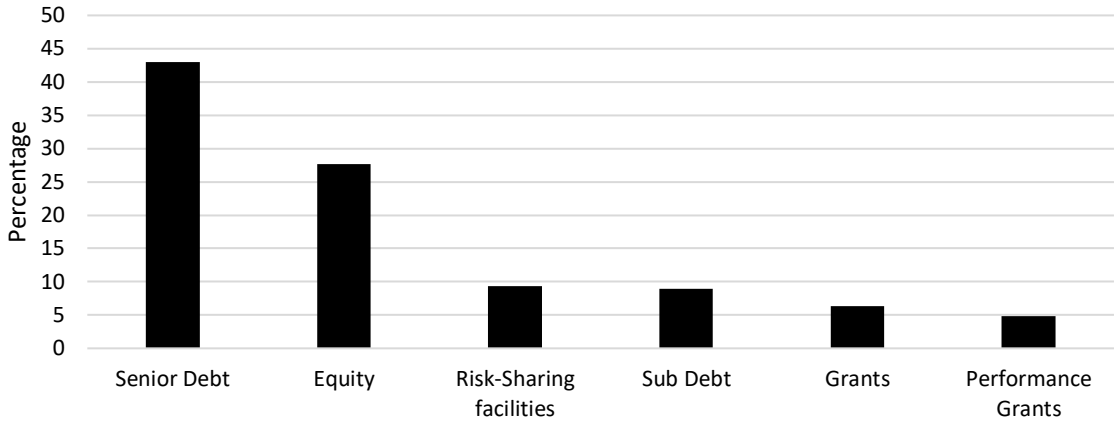
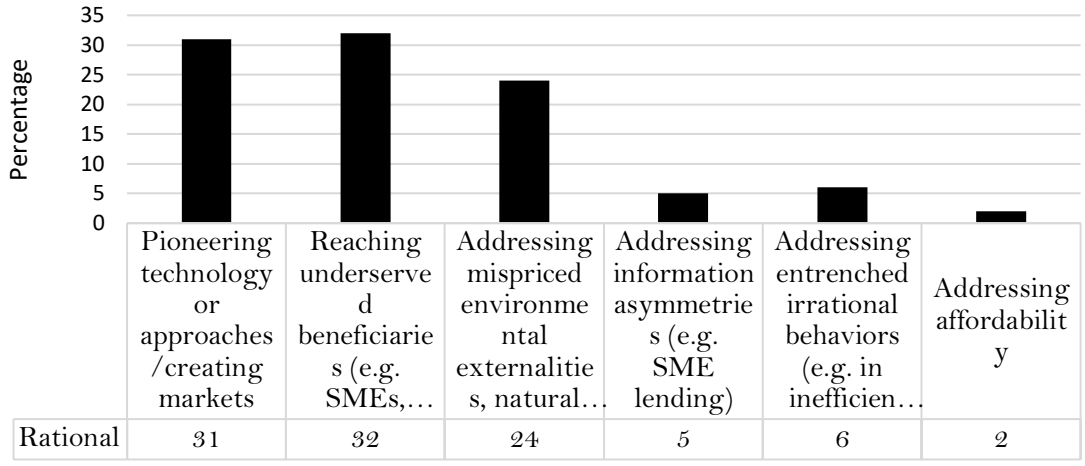


Figure 1: Concessional Commitments by Instrument, 2014-2016
Source: International Finance Corporation (2017)



	Pioneering technology or approaches /creating markets	Reaching underserved beneficiaries (e.g. SMEs,…	Addressing mispriced environmental externalities, natural…	Addressing information asymmetries (e.g. SME lending)	Addressing entrenched irrational behaviors (e.g. in inefficien…	Addressing affordability
Rational	31	32	24	5	6	2

Figure 2: Rationale for using blended finance, 2014-2016
Source: International Finance Corporation (2017)

Patient, flexible and risk tolerant financing

Assuming local intermediaries exist, a recommended investment strategy by DFIs in fragile states would be to use local intermediary institutions to channel capital into these environments which can bring overhead costs down and leverage on the superior contextual knowledge of local intermediaries (CDC, 2019). A DFI, the British International Investment (2019), reported that based on previous experience in fragile states, a level of flexibility and diversification is required by DFIs when selecting which sectors to invest in. In some fragile economies, traditional ideas of which sector to invest in and which ones not to may be cast aside (CDC, 2019). DFIs are expected to invest in traditional sectors such as infrastructure but in certain fragile economies, it may be more beneficial to invest in other emerging sectors. Some emerging sectors can require more attention and face greater execution risk, therefore DFIs should play a role in identifying sectors which are below the government radar, and which provide goods and services which have an unmet demand. The British International Investment has invested in commercial property and car hire firms in Sierra Leone. These are sectors which on the surface do not reflect a development agenda but based on local knowledge do actually facilitate development in the area (CDC, 2019). DFIs also have a role

to play in implementing more risk tolerant investment strategies in fragile economies through, for example, increasing equity participation in environments where early-stage equity markets are underdeveloped. The advantages of equity investment for DFIs are that they provide a degree of patience as there is less pressure for firms to generate immediate returns. They also allow for firms to prioritise long-term growth and provide a sense of stability during times of volatility (Carter, 2020). Equity investments also allow for DFIs to have better control of management decisions as in more fragile economies, a more direct approach is required.

Addressing inequalities

Conflict affects people differently; however, the reconstruction post-conflict provides an opportunity for transforming gender relations in a positive direction. DFIs have a role to play in addressing gender inequalities in fragile states, in order to provide inclusive growth and ensure the full participation of women within the economy (AfDB, 2022). As part of their strategy to address fragility, the AfDB has developed a targeted program for empowerment of women to strengthen their roles as agents of change in the peace and state-building process (AfDB, 2022). The AfDB has highlighted that the political, economic, and legal empowerment of women is a key element that will suffuse their work in fragile economies. The gender strategy guides the engagement of the AfDB on the continent in terms of supporting gender equality through national development strategies and through their own operations. Their strategy involves encouraging the participation of women in peace and state-building at all levels and paying attention to the impact of gender-based violence faced by women during conflict situations (AfDB, 2022). The AfDB follows the High-Level Panel on Fragile States recommendations regarding addressing fragility by supporting women's livelihoods through entrepreneurship support and securing land tenure for women in building resilience (AfDB, 2022). The AfDB gender strategy provides another role for DFIs in supporting health and education services in fragile states in order to ensure women and girls' non-discriminatory access to and participation in these services.

Supporting Trade Finance

The experience of the International Finance Corporation (IFC) in fragile states has led to the rise of other roles which DFIs can play in fragile economies (IFC, 2019). One such role is supporting trade financing in fragile states. The IFC has supported trade finance in fragile economies through the Global Trade Finance Program (GTFP) which extends and complements the capacity of banks to deliver trade financing by providing risk mitigation in new or challenging markets where trade lines may be constrained (IFC, 2019). Trade is essential for growth and is a key driver of integration and opportunities for local enterprises.

Providing advisory services to firms and government

Because of their experience, knowledge, and expertise, DFIs have a role to play in terms of providing advisory services to governments and firms in fragile economies (AfDB, 2019). This was evident in Sierra Leone where the AfDB provided critical strategic advisory services during the preparation of the country's third generation agenda for prosperity 2013-2018. The AfDB provided advice on gender empowerment, international competitiveness, and green growth. Giving advice on green growth and transitioning to renewables is important in fragile

economies, however, DFIs should prioritise economic growth above green initiatives. The AfDB continues to play a leadership role in sectors such as transport and water in the country (AfDB, 2019). The IFC has also played a role in providing advisory services in fragile states through the Creating Markets Advisory Window program and the Fragile and Conflict Situations Africa program (IFC, 2019). Both programs have provided advice in fragile economies to build capacity and strengthen the private sector. The Africa program in particular has provided advisory resources for investment teams that work on early-stage opportunities in fragile states in Africa (IFC, 2019). Both experiences have shown how DFIs can play a larger role in advising governments and firms in fragile states.

Types of investment required in fragile economies

Fragile economies need investment which creates jobs, spurs economic growth, generates tax revenues, bolsters infrastructure, and creates a sense of hope for their people (Levy, 2016). The creation of decent jobs is key to reducing poverty and improving the standard of life in fragile states. DFIs should focus on replacing informal unstable jobs with formal stable jobs or rather improve the quality of informal jobs (Carter & Petr Sedlacek, 2019). Collier, et al. (2021) has emphasized the need for catalytic investments in fragile states as they affect multiple nodes of an economic network. These types of investments have a direct and indirect multiplier effect on the entire economy and result in knowledge transfers, capacity building, reduction in the price of intermediate inputs and economies of specialisation. DFIs also have to promote investments that are conflict sensitive as the inflow of resources in resource-scarce fragile environments will cause locals to fight amongst each other for control of these resources which may cause more harm than good (Collier, et al., 2021). These conflict sensitive investment strategies involve sector and project-specific analysis and accounting for the evolving nature of the conflict cycles. Before the establishment of the fragile and conflict situations Africa program, the IFC had implemented the Conflict Affected States in Africa program which provided a conflict sensitive approach based on the assessment of the political risks associated with an investment. The program also analysed the fragility induced impacts that an investment could provoke and accordingly adjusted for it (IFC, 2013).

Challenges faced by Development Finance Institutions in fragile economies

Challenges facing DFIs in their efforts to invest in fragile economies include macroeconomic elements such as the political and economic instability in fragile states which create difficult environments for DFIs and the private sector to thrive (Collier, et al., 2021). Other elements include the infrastructure deficiencies. The weak human capital in fragile states also poses a challenge to DFIs in terms of investing in them as it limits the supply of investment opportunities as there is a limited work force available (Maier, 2010). The weak physical and mental health of individuals in fragile states may affect the supply of productive labour (Maier, 2010). Due to acts of violence and conflict, individuals in fragile states are exposed to traumas on a scale not known to the rest of the world, which will likely cause psychological and mental health issues. As such, even when DFIs provide support for pioneering firms in such states in order to create job opportunities, these firms may not reach their full productive capacity.

Human development and training may be required to increase the overall cost of investment (Maier, 2010). Other challenges such as lack of state capacity and lack of information on local markets will also increase the overall costs of operating in fragile economies. Another challenge that DFIs face when investing in fragile states is the rigid investment requirements that have been placed by DFI shareholders which the DFIs should meet. These investment requirements can include investing at commercial terms, losses and risk aversion and maintaining environmental, social and governance standards (Collier, et al., 2021). These requirements are standard and therefore unsuitable for different environments which presents a challenge and as such limits the DFIs' ability to make development impact in fragile economies. Investing in fragile economies does have higher risks, inevitable financial losses and returns may not materialise until after many years. As stated before, DFIs investing in fragile states requires patience, which may not be part of the investment requirements made by shareholders.

Besides limits posed by shareholders, DFIs themselves can have internal barriers towards investing in fragile economies (Collier, et al., 2021). These include a corporate structure which prioritizes successful deal making, which will encourage risk aversion behaviour which will steer DFIs into investing in high income countries, where returns are guaranteed (Collier, et al., 2021). This is fear of failure behaviour which will limit the DFIs' reach into fragile economies, which deserve greater assistance than already developed or developing countries and will have a larger development impact on the states that require it more. This risk aversion behaviour can also be motivated by the reputational risk associated with investing in fragile economies as environmental, social and governance standards may not be met and as such create a bad reputation for the DFIs. Standards should be adjusted to account for the scope of work required in these environments and should not be compared with standards in place in more developed countries (Collier, et al., 2021).

Policy considerations for improving development finance in fragile economies

Having examined some of the challenges facing DFIs in investing in fragile economies, it is clear that some of these challenges can be addressed by changes in policies within DFIs that will allow them to play a more meaningful role in fragile economies. The first would be a change in the corporate culture of DFIs which fosters risk aversion and deal making. In fragile economies, success should be redefined away from deal making and more towards job creation. DFIs' staff members should be rewarded also for the productive jobs created from projects and not only on the basis of deals and transactions made. Fragile economies carry more risk and as such high-risk tolerant policies are required from DFIs and room for failure should be provided, as there will be knowledge gained from such experiences that will provide more insight into the market structures that can be used for better project preparation in the future. It does remain unclear how much risk is enough, as too much risk and recklessness can also be a problem and proper risk mitigation techniques will therefore be required.

One such technique would be for DFIs to establish a working relationship with governments and civil society groups within these fragile economies in order to gain more insight from those within the country, in order to better scope the potential for investment in certain sectors. Working relationships should also be established amongst multiple DFIs themselves in multiple forms. One such form can be through the co-financing of projects in fragile economies in order to share risk and develop more expertise. The collaboration amongst DFIs can also

go further into information sharing on experiences in different fragile states. The Commission for State Fragility, Growth and Development from the International Growth Centre of the London School of Economics held a meeting with multiple DFIs across the world. The participating DFIs agreed to cooperate in rolling out pilot interventions in some fragile states. The participating DFIs including the AfDB agreed to enhance collective dialogue amongst development agencies to leverage on diverse skills and improve complementarity, manage financial and non-financial risks, and work together on reforms to strengthen business environments in fragile states (AfDB, 2020).

Case study of successful investments in fragile states

Construction Sector in Liberia

Fragility in Liberia is characterised by poor governance and fifteen years of brutal conflict, which have made the country one of the poorest in the world, as ordinary citizens feel ostracized from the political and decision-making process. Fragility is also manifested in the failure of the state to deliver basic services to citizens. Liberia has one of the worst public sectors in West Africa, with inadequate quality of policy delivery and public investment management, according to the AfDB's 2020 Country Resilience Fragility Assessment. Therefore, youth are more likely to express their displeasure toward government through constant demonstrations. Moreover, access to opportunities is determined by background, the urban-rural divide, social classes, ethnolinguistic identities, and education leading to various forms of exclusion. Social mobility for marginalized groups is low due to multidimensional inequalities, livelihood constraints, low human development and emerging forms of intolerance. Liberia identified infrastructure reconstruction and capacity building as being key to the country's recovery, economic growth, and poverty reduction after almost 14 years of civil war which undermined its human development and devasted the country's construction sector. In 2012, it was reported by the Ministry of Public Works that only about 970 construction firms operated in the country, which were mostly shell companies set up for contract farming and subcontracting, and as such were unable to execute public work (McKechnie, et al., 2018). The Doing Business Report ranked Liberia 179 out of 189 countries in 2016, as the conditions for doing business in the country were very severe (World Bank, 2016). The underdevelopment of the local construction sector in Liberia was attributed to the lack of a business conducive environment in the state which was a result of a number of factors. The local construction sector also lacked management and engineering capacity which means the local contractors are too incapacitated to manage large projects. There was also a lack of financing from the financial sector which in itself was underdeveloped and as such contractors were unable to source credit to fund projects. The weather conditions in Liberia also restricted the progress of construction projects as heavy rainfalls are experienced throughout the year.

Other challenges in the sector include the lack of equipment within the construction sector and when importing equipment into the country, logistical constraints were experienced due to the lack of road and port infrastructure. Road infrastructure is particularly important not only to facilitate trade but also to connect individuals across various parts of the country. Such investment into road infrastructure was required in Liberia but because of its post conflict nature, which results in substantial risk, investors were unlikely to participate. In order to address the issues of lack of capacity in the construction sector and the lack of road infrastructure in the state, the Liberian government engaged the foreign private sector in

highway construction and maintenance through Output and Performance Based Road Contracts (OPRC). The agreement was that a contractor would be awarded a 10-year contract to produce a detailed design and rehabilitate a highway and provide maintenance throughout the period of the contract. The infrastructure would be the property of the government though the contractor would be paid throughout the period of the contract (McKechnie, et al., 2018). The OPRC approach is preferred in fragile states as because of its long-term nature, risk is reduced as the government is more likely to make payments to the contractor and not default. It is also ideal for the contractor to maintain the infrastructure and not the government as the contractor would have better knowledge and capacity.

The project for Liberia was for the Red Light – Gate 15 – Gbarnga – Ganta – Guinea Border and Cotton Tree to Buchanan roads (Gericke, et al., 2014). The World Bank administered Liberia Reconstruction Trust Fund provided funding for the OPRC project with a USD 108,9 million grant combined with an International Development Association credit of USD 67,7 million and additional government funding of USD 72,8 million (World Bank, 2017). The World Bank further extended an additional credit of USD 90 million to scale up the project by including an additional road and to finance road safety improvements. Once Liberia put in place the first OPRC, two Chinese contractors were successful and were responsible for the construction and the maintenance of the infrastructure for the 10-year duration. One of the Chinese contractors employed and trained 900 Liberians and 54 Chinese for the construction of the roads as well as for equipment operation. On the construction site, mobile plant operators, surveyors and general workers were Liberian with only a few workers being foreigners (McKechnie, et al., 2018).

This case study is an illustration of how an initiative-taking government leadership, supported by multilateral development banks was critical in bringing private participation into fragile economies. With this entire experience, the World Bank, being a partner and financier, has gained invaluable knowledge with regards to how OPRC can be incorporated and used to foster infrastructure investment in fragile states. This knowledge can be shared with other development finance institutions to establish an investment path into fragile states. Beyond the construction sector, the AfDB through the Government of Liberia, has invested in transport and energy infrastructure in the country, and indirectly, through multi-country assistance benefitting the other three Mano River Union countries (Sierra Leone, Guinea, and the Republic of Côte d'Ivoire). As of August 2022, the AfDB's investment portfolio for Liberia comprised 18 ongoing and recently approved operations, with a total financial commitment of USD 478 million. The active portfolio spreads across five sectors and is heavily invested in infrastructure, roads (USD 262 million) and energy (USD 105 million). The transport sector accounts for the largest share of the portfolio (56 percent), followed by energy (22 percent), agriculture and rural development (12 percent), and multi-sectors (4 percent). In the energy domain, the AfDB is co-sponsoring investments, cooperating with other development partners, aimed at providing modern, adequate, and affordable energy systems in Liberia. Core investments include renewable energy, power transmission and distribution, and rural electrification.

CONCLUSION AND RECOMMENDATIONS

The first objective of this research was to investigate and establish an approach for DFIs to navigate fragile environments and which roles they should play in fragile economies. The second objective was to determine how DFIs can identify and participate in investment sectors with the most growth potential within these fragile economies. The research first analysed fragility, and the measures required to escape it from an economic, political, and social point of view. The study also investigated key challenges facing DFIs in fragile economies and recommended key policy considerations for improving development finance in these economies. The findings from the study highlight that measures required to escape fragility include structural changes, pioneering firms, and state building. The study also highlights the roles DFIs can play in fragile states such as supporting pioneering firms, providing patient, flexible and risk tolerant financing and addressing gender inequalities. Other added roles include supporting trade finance, providing advisory services to firms and governments and fostering infrastructure development.

The study also found that in order to navigate fragile environments, a recommended investment strategy by DFIs would be to use local intermediary institutions to channel capital into these environments. This can bring overhead costs down and leverage on the superior contextual knowledge of local intermediaries. The challenges facing DFIs in fragile economies include macroeconomic elements, infrastructure deficiencies and rigid investment requirements that have been placed by DFI shareholders which the DFIs should meet. DFIs themselves can have internal barriers towards investing in fragile economies. These include a corporate structure which prioritizes successful deal making and encourages risk aversion. These challenges can be addressed by changes in policies within DFIs that will allow them to play a more meaningful role in fragile economies. These findings recommend that investment committees in DFIs should make use of them when reviewing transactions from these environments and when identifying investment sectors in fragile states. The main limitation facing this research was the lack of available data and low response rate from key informants when compiling the case study analysis which limited the analysis to one country, Liberia to the exclusion of Afghanistan and Mauritius as comparative case studies. Areas for future research include further research on specific financing instruments and an analysis of their development impact in fragile states.

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INFRASTRUCTURE DEVELOPMENT AS A CATALYST FOR ECONOMIC GROWTH IN SOUTH AFRICA

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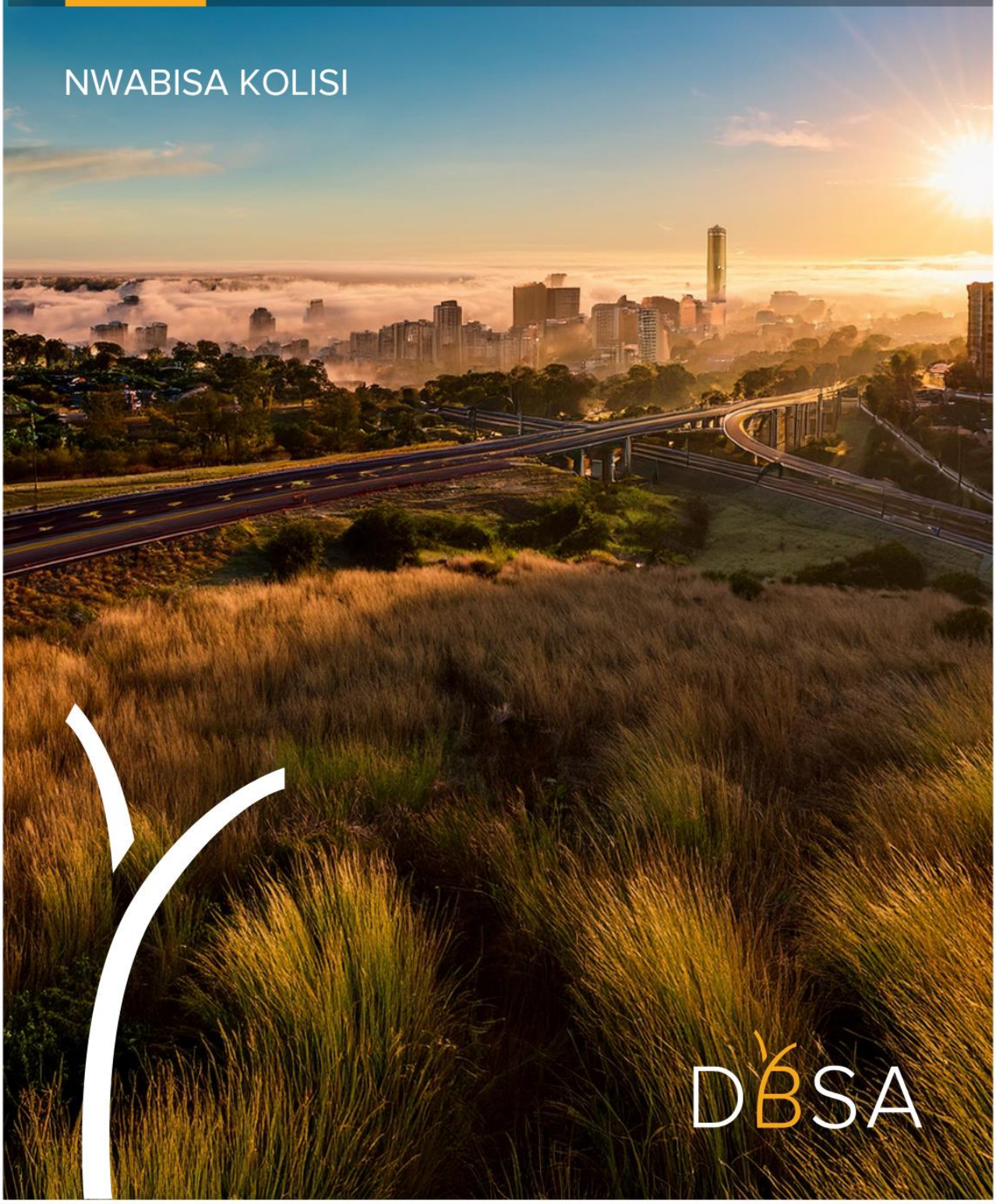

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INFRASTRUCTURE DEVELOPMENT AS A CATALYST FOR ECONOMIC GROWTH IN SOUTH AFRICA

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ABSTRACT

The study investigates the long-run relationship between infrastructure investment and economic growth in South Africa from 1994 to 2022. The South African government has prioritized infrastructure investment to drive economic growth, but challenges like underinvestment, power shortages, and political instability have hindered its progress. The study employs the Autoregressive Distributed Lags (ARDL) model to analyze data from Statistics South Africa and the South African Reserve Bank, with GDP as the dependent variable and infrastructure investment, government consumption expenditure, household consumption expenditure, and trade openness as independent variables. The results show that infrastructure investment, measured by gross fixed capital formation (GFCF), has a statistically significant positive relationship with economic growth in both the long and short run. A 1% increase in infrastructure investment leads to a 0.1% increase in GDP in the long run. Additionally, household consumption expenditure, government consumption expenditure, and trade openness positively influence economic growth in the short run. The study further demonstrates that 29% of short-run disequilibrium is corrected toward long-run equilibrium, indicating a stable relationship. Diagnostic tests confirm the model's validity and stability. Overall, the findings emphasize that consistent infrastructure investment is crucial for sustained economic growth in South Africa.

Keywords: Economic Growth, Infrastructure Investment, South Africa, Consumption, Expenditure, Political Instability

INTRODUCTION AND BACKGROUND

The South African government's major focus is achieving the socio-economic goals of reducing unemployment, poverty, and inequality (National Development Plan, 2012). In South Africa, unemployment, poverty, and inequality levels remain high and the economic outlook remains constrained by the low growth potential (Asuelime, 2018). South Africa's economy has been growing at less than 2% from 2014 to 2019 (Statistics South Africa, 2022). The low economic growth rates can be attributed to, among others, low foreign and domestic investment, power outages, and deterioration of infrastructure quality (National Treasury, 2019).

The South African government is fully committed to infrastructure investment to grow the country's economy and continues to fund economic and social infrastructure facilities and activities (Cumming *et al*., 2017; Mbeki *et al.,* 2019; National Treasury, 2019). South Africa's infrastructure investment incorporates roads, transportation networks, power stations, communication networks, schools, hospitals, safe water, and sanitation (National Treasury, 2019). Infrastructure investment is regarded as a means of achieving economic growth, economic development, and poverty alleviation in South Africa (Gnade, 2021).

Infrastructure generally refers to physical structures, facilities, and systems such as power supplies, water supplies, roads, buildings, schools, hospitals, and communication networks to provide essential services for public use (Stupak, 2018). The World Bank (2018) divides infrastructure stock into economic infrastructure and social infrastructure. Furthermore, infrastructure includes institutional infrastructure such as banking and civil administration (Torrisi, 2009). In this study infrastructure investment is defined as the allocation of funds toward the development, improvement, and maintenance of essential physical structures and systems that support economic activities (Yapicioglu *et al*., 2017). These include communication networks, transportation networks, water and sanitation systems, energy facilities, and public amenities like hospitals and schools (Stupak, 2018).

South Africa continues to experience underinvestment in infrastructure development and institutional factors have led to a deterioration of the quality of the infrastructure in the country (World Bank, 2018). Furthermore, investment in key economic infrastructure such as the energy and transport sectors has lagged far behind the domestic demand (Mahori, 2022; World Bank, 2018). Infrastructure investment has been on a downward trajectory over the recent few years recording 5% from 2020 to 2022 (Stats SA, 2023).

This study assessed the relationship between infrastructure investment and South African economic growth using the autoregressive distributed lags (ARDL) model of analysis. It is hoped that the findings of this study will contribute knowledge and insights into efforts that seek to increase infrastructure investment to foster economic development and growth in South Africa.

RESEARCH GOALS

The purpose of this study is to investigate the long run relationship between infrastructure investment and economic growth in South Africa from 1994 to 2022.

OVERVIEW OF ECONOMIC GROWTH AND INFRASTRUCTURE INVESTMENT IN SOUTH AFRICA

The South African GDP growth rate registered 1.1% in 2017 and registered a significant decline of -6.3% by 2020 due to low investment growth, shortages of electricity supply, political instability, and the COVID-19 pandemic (Stats SA, 2022; World Bank, 2020). South Africa's GDP growth rate rebounded to 4.7% in 2021 due to the country moving out of the COVID-19 pandemic and the hard lockdown period, increased economic activities, and short-term countercyclical as well as fiscal and monetary policy measures (Stats SA, 2022).

The South African government continues to prioritise and expand infrastructure investment as part of the national growth and development strategy. This is exemplified by strategy documents such as the Growth Employment and Redistribution, Accelerated and Shared Growth Initiatives for South Africa, the National Development Plan, and the Infrastructure Plan 2050 (National Treasury, 2019). However, South Africa continues to have critical infrastructure needs partly because of underinvestment, poor maintenance, and neglect of infrastructure networks which continue to depress economic growth (National Treasury, 2020:15; Makhathini, Mlambo & Mpanza, 2020). The country continues to experience underinvestment and deterioration in the quality of infrastructure due to, among others, misappropriation of funds, and increasing infrastructure bottlenecks (Meyer & Sanusi, 2019; Makhathini, Mlambo & Mpanza, 2020).

LITERATURE REVIEW

The theoretical underpinnings of the study are based on the endogenous growth theory (Romer 1986, 1990) and the government expenditure in a simple model of endogenous growth (Barro, 1990). The endogenous growth theory assumes that labour, human capital, physical capital as well as technological change are primary sources of economic growth (Romer, 1986). Furthermore, the theory assumes that economic growth tends to be faster in countries that have a relatively large stock of capital (Romer, 1990). In terms of government expenditure in a simple model of endogenous growth, infrastructure investment has a positive effect on economic growth in which final output is a function of both public-sector infrastructure services and private-sector investment (Barro,1990; Perkins, 2006). The theory postulates that public investment encourages new private investment to take advantage of the higher productivity it creates, thus increasing economic growth (Maalim, 2022). Nonetheless, a negative relationship can exist between infrastructure investment and economic growth when public investment crowds out private investment (Fosu, Getachew & Ziesemer, 2016).

Some empirical studies on the relationship between infrastructure investment and economic growth show that infrastructure investment has a positive relationship and impact on economic growth (Kumo, 2012; Palei, 2015; Mbanda & Mabugu, 2016; Sharma & Tenyana, 2019; Zhang *et al*., 2021; Matsolo, 2021; Du, Zhang & Han, 2022; Cheng & Zhang, 2023). Other studies have established a negative relationship between economic growth and infrastructure investment (Younis, 2014; Vuyeka, 2015; Stungwa & Daw, 2021; Apurv & Uzma, 2020). It can be learned that the main reason for the difference in the results of these studies lies in the different methodologies used, different study periods explored, and country specifics.

DATA AND METHODOLOGY

Most of the data on the variables were obtained from Statistics South Africa and the South African Reserve Bank. GDP is measured at constant 2015 prices. Infrastructure investment is the sum of gross fixed capital formation (GFCF) of general government infrastructure investment and GFCF infrastructure investment by public corporations which together form aggregate public economic infrastructure investment in the country at constant 2015 prices. Both final consumption expenditures by the general government and households are measured at constant 2015 prices. Trade openness is the sum of exports and imports measured at constant 2015 prices. All the variables are transformed into logarithms. These control variables have an impact on economic growth. The study will cover the period from 1994 to 2022. The rationale behind choosing this study period is to examine the effect of infrastructure investment on economic growth in South Africa since the advent of democracy.

Methodology

The study uses quantitative research methodology. The Autoregressive Distributed Lags (ARDL) model is selected for the empirical analysis. Unlike Engle-Granger and Johansen, the ARDL approach is suitable for this study as it can be applied with a small number of observations and can be used regardless of the order of integration of the variables, whether they are I (0) or I (1), or a mixture of both (Pesaran and Shin, 1999; Odhiambo, 2013).

The model specification to investigate the relationship between economic growth, infrastructure investment, final government consumption expenditure, final household consumption expenditure, and trade openness is based on a simple multivariate framework where the empirical model is specified as follows:

$$LGDP_t=\beta_0+\beta_1 LGFCF_t+\beta_2 LGOVEXP_t+\beta_3 LCONSUMP_t+\beta_4 LTR_t+\varepsilon_t \quad (5.1)$$

Where:

L represents logarithms, β_o is the intercept, and β_1, β_2, β_3, and β_4, are coefficients to be estimated.

GDP represents the measure of economic growth, GFCF is the indicator for total infrastructure investment from the government sector, public corporations, and private investment enterprise as a percentage of GDP, GOVEXP represents final general government consumption expenditure as a percentage of GDP, CONSUMP is the indicator of the final household consumption expenditure as a percentage of GDP, and TR is trade openness thus the sum of a country's export and imports, and ε is the error term.

Unit root testing

Unit root tests are conducted before the empirical estimations to determine the order of integration of the variables. The Augmented Dickey-Fuller (1981) test and the Phillips and Perron test (1988) are used in this study.

ARDL bound testing

According to Harris (1995:52), if two series appear to move together over time, it indicates a long-run relationship among the variables. For example, suppose two variables are integrated of order one 1(1) and the residuals obtained from regressing Yt and Xt are 1(0), the two series are co-integrated. This study utilised the ARDL bounds testing approach for the existence of a long-run relationship between variables developed by Pesaran, Shin, and Smith (2003). The test can be used irrespective of whether variables are purely I (1), I (0), or a mixture of variables of different orders of integration. The technique cannot be used in the presence of I (2) variables.

The bound testing approach is based on a VAR model which can be specified as follows:

$zt = c0 + c1t + \sum \varphi i \Delta zti + \varepsilon t \; p \; i=1$ (5. 2)

where $c0$ is a vector of intercepts, $c1$ is a vector of trend coefficients and p is the lag length. The vector error correction model (VECM) is specified as follows:

$\Delta zt = c0 + c1t + \Pi zt-1 + \sum \Gamma i \Delta zt-i + \varepsilon t \; p \; i=1$ (5.3)

Where Π and Γ are the long-run and short-run coefficient matrices, respectively. The null hypothesis of no long-run relationship is tested against the alternative hypothesis using the Wald test (F-statistics). Pesaran *et al.* (2003) provided critical values for the F-test. If the F-statistic is greater than the upper critical value, the null hypothesis is rejected. If the F-statistic is less than the lower critical value, the null hypothesis is not rejected irrespective of the order of integration of the variables. If the F-statistic falls between the upper and lower critical values, the results are inconclusive.

The long-run relationship between GDP, total GFCF, government consumption expenditure, household consumption expenditure, and trade openness are specified as an ARDL (p,q,p,q,p,q) dynamic specification which will be used for this relationship as follows:

LGDPt=$\lambda 1 i$LGDP$t-1+\delta 10 i$LGFCF$t+\delta_2 0 i$LGOVEXP$t+\delta_3 0 i$LCONSUMP$t+\delta_4 0 i$LTR$t+\delta-1-1 i$L GFCF$t--1+\delta_2-1 i$LGOVEXP$t--1+\delta_3-1 i$LCONSUMPT$t--1+\delta_4-1 i$LTR$t--1+\mu i+\varepsilon t$
(5.4)

The error correction representation of the ARDL model is specified as follows:

Δ LGDPt= ϕi(LGDP$t-1$- $\theta 0 i$- θ $1 i$ LGFCF$t-1+\theta_2 i$LGOVEXP $t-1+\theta_3 i$ LCONSUMP $t-1+$ $\theta_4 i$ TR $t-1$)+ $\delta i 01 \Delta$ LGFCF+ $\delta i 02 \Delta$LGOVEXP+$\delta i 03 \Delta$ LCONSUMP + $\delta i 04 \Delta$ LTR + $\mu i+\varepsilon it-1$
(5.5)

Where the Δ is defined as the first difference operator, t is the time trend. It is assumed that the residuals are (ε)normally distributed and white noise.

Diagnostic testing

Diagnostics and stability tests were conducted on the ARDL model to ascertain the goodness of fit of the model. The diagnostic test performed in this study includes the Breusch (1978) – Godfrey (1978) LM test for serial correlation, the Breusch and Pagan (1979) test for heteroscedasticity, as well as the residual normality test for checking the model validity of the estimated coefficients and the stability of the model.

EMPIRICAL RESULTS

The empirical results of the relationship between infrastructure investment and economic growth in South Africa are presented in this section.

Summary statistics

Table 1 below shows the descriptive statistics of the relationship between infrastructure investment and economic growth from 1994 to 2022.

Table 2: Descriptive statistics

R' million	GDP	Government consumption expenditure	Household consumption expenditure	Infrastructure investment	Trade openness
Mean	3 654 152	691 910	2 287 540	152 523	1 986 935
Median	3 856 572	728 133	2 407 392	180 152	1 385 589
Maximum	4 599 261	900 044	3 066 585	295 024	4 312 584
Minimum	2 389 241	472 455	1 362 465	24 127	202 309
Std. Dev.	772 010	156 457	568 247	100 720	1 139 649
Jarque-Bera	2.976851	3.134598	2.817691	3.437178	1.974497
Probability	0.225728	0.208608	0.244425	0.179319	0.372600
Observations	29	29	29	29	29

Source: Author's construction

As can be seen in Table 1 above, the average value of South Africa's GDP during the period under review was R3.7 trillion, and the mean government consumption expenditure and household consumption expenditure were R691 billion and R2.3 trillion, respectively. The average value of infrastructure investment over the same period under consideration was R152 billion, average trade openness was R1.6 trillion. The minimum GDP in the country of R2.4 trillion was recorded in 2020, whereas the maximum GDP of R4.6 trillion was recorded after the country moved out of the hard lockdown period, increased economic activities, and implemented short-term countercyclical fiscal and monetary policy measures (Stats SA, 2021). The minimum infrastructure investment in the country was observed in 1994 recording R24 billion, whereas the maximum infrastructure investment of R295 billion was seen in 2016. Infrastructure investment has been on a downward trajectory over the recent few years (Stats SA, 2023).

Unit root test results

The unit root tests are run with a trend term and the unit root results are presented in Table 2 below.

Table 3: Unit root test results intercept and trends

Variables	Level		1st difference	
	ADF test	PP test	ADF test	PP test
LGDP	-0.216	-0.216	-3.480*	-4.730***
LGFCF	-1.173	-0.518	-3.249*	-3.288*
LHCE	-0.794	-0.791	-3.894**	-4.570***
LGCE	-1.008	-1.776	-3.107*	-5.094***
LTR	-2.057	-1.939	-4.019**	-5.972***

Source: Author's construction. Note: (***), (**), and (*) indicate significance at 1%, 5%, and 10%, respectively.

As can be seen Table 2, with a trend term included the ADF and PP tests suggest that all the variables are non-stationary at levels I(0)) and all the variables become stationary at the first difference I (1). The variables in the study are a mixture of I (0) and I (1) and therefore the estimation technique chosen is the ARDL bound cointegration test proposed by Pesaran, et al. (2001).

Bound testing cointegration results

The application of the ARDL bound test in examining the long-run relationship among the variables entails the estimation of an Unrestricted Error Correction Model (UECM) in first difference form (Khobai, et.al 2016:80). The results of the ARDL bound test are presented in Table 3.

Table 4: Bound test cointegration results

F-statistics	Critical values					
	1%		5%		10%	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
3.495	3.29	4.37	2.56	3.49	2.2	3.09

Source: Author's construction drawn from EViews 12 iterations

The ADRL bound results reported in Table 3 reveal that the computed F-statistics are above the upper bound values at a 5% significance level for South Africa. Following these results, the variables are said to be cointegrated, suggesting the rejecting of the null hypothesis that there is no cointegration. The results imply the presence of a long run cointegration relationship among the variables.

Following the finding of the existence of a long-run relationship among the variables, the long-run and short-run dynamics between the variables are estimated. The Akaike information criteria (AIC) is the model selection criteria.

ARDL long-run and short-run estimates

The long-run and short-run estimates of the relationship between infrastructure investment and economic growth in South Africa are presented in Table 4.

Table 5: Empirical results Dependent variable GDP

Long-run	Coefficient	t-Statistic	Probability
Log Gross fixed capital formation	0.118	2.257	0.035**
Log Household consumption expenditure	0.034	0.078	0.938
Log Government consumption expenditure	0.047	0.269	0.790
Trade openness	0.111	1.447	0.163
Short run			
Log Gross fixed capital formation	0.033	6.468	0.003***
Log Household consumption expenditure	0.625	12.728	0.000***
Log Household consumption expenditure (-1)	-0.615	-5.678	0.000***
Log Government consumption expenditure	0.184	2.525	0.020**
Log Government consumption expenditure (-1)	-0.171	-3.959	0.000***
Trade openness	0.031	2.326	0.030**
ECM	-0.280	-10.596	0.000***

Source: Author's construction based on own computations. Note: (***), (**), and (*) indicate significance levels at 1%, 5% and 10%, respectively.

Gross fixed capital formation (GFCF) has a positive and statistically significant relationship with economic growth both in the long and short run in South Africa. These results are consistent with Mbanda & Mabugu (2016) and Sharma & Tenyana (2019). The results suggest that a 1% increase in infrastructure investment leads to a 0.1% increase in economic growth in the long run. The results imply that infrastructure investment potentially boosts economic growth in South Africa both in the long and short run. Although it is statistically significant both in the short and long run, the impact of infrastructure investment on economic growth is less than 1% during the period reviewed. In this regard, if South Africa continues to invest in new productive infrastructure and maintains the existing infrastructure, this will eventually lead to growth for the economy (Makhatini, Mlambo& Mpaza, 2020).

Household consumption expenditure enhances the South African economic growth scenario. Government consumption expenditure is associated with a higher growth rate in South Africa both in the short and long run. Trade openness has a positive and insignificant relationship

with economic growth in South Africa in the long run while a positive and significant relationship with economic growth is reported in the short run.

The Error Correction Model (ECM) coefficient shows that 29% of the disequilibrium in the short run is corrected towards the long run. The error correction term is negative and significant at 1%, providing further evidence of a long-run relationship between the variables.

Diagnostic tests

The diagnostic tests for normality, heteroscedasticity, serial correlation, and stability were performed to validate the adequacy of the model. Breusch (1978) and Godfrey (1978) LM is selected for serial correlation test. Breusch and Pagan (1979) are chosen for the heteroscedasticity test. Normality is tested using the Jarque-Bera test under the null hypothesis that the residuals are normally distributed (Gujarati and Porter, 2009). The Ramsey test is used for model stability (Ramsey,1969). The diagnostic test results are shown in Table 5 below.

Table 6: Diagnostic test results

Dependent variable: SAGDP								
Country	**Jaque-Bera test**		**Serial Correlation LM test**		**Breusch-Pagan test**		**Ramsey's RESET test**	
	J. Bera	P-value	F-stat	P-value	F-stat	P-value	F-stat	P-value
South Africa	0.799	0.670	1.333	0.288	0.550	0.786	0.000	0.983

Source: Author's computation using SARB, Stats SA data (2023)

The diagnostic test results shown in Table 5 above show no evidence of model misspecification, heteroscedasticity, serial correlation, and instability as the respective null hypotheses are rejected. The results indicate that the ARDL model passed the diagnostic tests, suggesting that the model is adequate and robust for statistical inferences.

CONCLUSION AND RECOMMENDATIONS

This study investigated the impact of infrastructure investment on economic growth in South Africa using the ARDL model for the period 1994 to 2022. It included final government consumption expenditure, final household consumption expenditure, and trade openness as additional variables to form a multivariate framework. The study found that there is a long-run relationship between infrastructure investment and economic growth in South Africa. Furthermore, the results revealed that infrastructure investment has a positive and significant impact on economic growth both in the long and short run. The results imply that the South African government should ensure that its infrastructure development policies assist with scaling up new infrastructure and maintenance of the existing infrastructure to grow the South African economy.

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APPENDIX A: Data

Year	GDP R' million	Infrastructure investment R' million	Trade openness R' million	Household consumption expenditure R' million	Government consumption expenditure R' million
1994	2 389 241	24 127	202 309	1 362 465	502 660
1995	2 463 307	28 453	245 909	1 443 213	472 456
1996	2 569 229	31 203	296 156	1 507 750	490 434
1997	2 636 029	36 254	329 377	1 556 865	500 911
1998	2 649 210	45 720	372 425	1 583 993	489 788
1999	2 712 791	41 136	391 181	1 611 518	491 916
2000	2 826 728	41 748	486 768	1 678 206	506 322
2001	2 903 049	44 114	573 304	1 736 828	522 132
2002	3 010 473	52 681	727 494	1 791 931	546 001
2003	3 099 254	61 876	681 468	1 842 670	576 869
2004	3 240 412	68 383	754 230	1 957 662	607 082
2005	3 411 410	77 157	871 249	2 077 733	613 633
2006	3 602 579	95 156	1 106 330	2 260 081	636 751
2007	3 795 694	132 820	1 340 527	2 407 392	676 256
2008	3 916 816	180 152	1 723 011	2 436 546	728 133
2009	3 856 572	195 479	1 385 589	2 373 417	740 990
2010	3 973 802	188 020	1 540 216	2 508 374	738 924
2011	4 099 714	217 067	1 817 777	2 610 053	769 098
2012	4 197 952	225 114	1 982 291	2 694 257	805 940
2013	4 302 291	257 468	2 277 657	2 736 048	831 421
2014	4 363 118	266 327	2 459 637	2 755 751	847 435
2015	4 420 793	293 172	2 507 769	2 815 210	839 291
2016	4 450 171	295 024	2 658 747	2 834 426	856 222
2017	4 501 702	278 332	2 718 656	2 883 014	853 842
2018	4 571 783	266 411	2 922 164	2 974 191	863 117
2019	4 583 667	250 454	3 031 874	3 012 316	879 004
2020	4 310 327	222 233	2 822 230	2 827 579	887 166
2021	4 513 044	238 477	3 482 174	2 992 578	891 561
2022	4 599 261	268 628	4 312 584	3 066 585	900 045

Source: SARB (2023), Stats SA (2023)

APPENDIX B: ARDL Bound test, long- run and short-run results

ECM and F- Bound Test

ARDL Error Correction Regression
Dependent Variable: D(LGDP)
Selected Model: ARDL(1, 0, 1, 1, 0)
Case 2: Restricted Constant and No Trend
Date: 12/02/23 Time: 08:32
Sample: 1994 2022
Included observations: 28

ECM Regression
Case 2: Restricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LGOVEXP)	0.184313	0.032578	5.657566	0.0000
D(LHCEXP)	0.625054	0.031986	19.54127	0.0000
CointEq(-1)*	-0.280106	0.054711	-5.119769	0.0001

R-squared	0.954993	Mean dependent var	0.023390
Adjusted R-squared	0.951392	S.D. dependent var	0.023436
S.E. of regression	0.005167	Akaike info criterion	-7.592103
Sum squared resid	0.000667	Schwarz criterion	-7.449367
Log likelihood	109.2894	Hannan-Quinn criter.	-7.548467
Durbin-Watson stat	2.327659		

* p-value incompatible with t-bounds distribution.

F-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	3.494938	10%	2.2	3.09
k	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37

Long run results

ARDL Long Run Form and Bounds Test
Dependent Variable: D(LGDP)
Selected Model: ARDL(1, 0, 1, 1, 0)
Case 2: Restricted Constant and No Trend
Date: 12/02/23 Time: 08:47
Sample: 1994 2022
Included observations: 28

Conditional Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.083994	0.747727	4.124491	0.0005
LGDP(-1)*	-0.280106	0.126953	-2.206380	0.0392
LGFCF**	0.033067	0.009961	3.319741	0.0034
LGOVEXP(-1)	0.013261	0.049144	0.269835	0.7901
LHCEXP(-1)	0.009638	0.125939	0.076529	0.9398
LTR**	0.031138	0.013382	2.326843	0.0306
D(LGOVEXP)	0.184313	0.072982	2.525459	0.0201
D(LHCEXP)	0.625054	0.054970	11.37092	0.0000

* p-value incompatible with t-Bounds distribution.
** Variable interpreted as Z = Z(-1) + D(Z).

Levels Equation
Case 2: Restricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LGFCF	0.118051	0.052283	2.257953	0.0353
LGOVEXP	0.047342	0.175569	0.269650	0.7902
LHCEXP	0.034408	0.436835	0.078768	0.9380
LTR	0.111167	0.076785	1.447762	0.1632
C	11.01008	4.382810	2.512106	0.0207

EC = LGDP - (0.1181*LGFCF + 0.0473*LGOVEXP + 0.0344*LHCEXP +
0.1112*LTR + 11.0101)

F-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	3.494938	10%	2.2	3.09
K	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37
			Finite Sample:	
Actual Sample Size	28		n=35	
		10%	2.46	3.46
		5%	2.947	4.088
		1%	4.093	5.532
			Finite Sample:	
			n=30	
		10%	2.525	3.56
		5%	3.058	4.223
		1%	4.28	5.84

Short run results

Dependent Variable: LGDP
Method: ARDL
Date: 12/02/23 Time: 08:52
Sample (adjusted): 1995 2022
Included observations: 28 after adjustments
Maximum dependent lags: 1 (Automatic selection)
Model selection method: Akaike info criterion (AIC)
Dynamic regressors (1 lag, automatic): LGFCF LGOVEXP LHCEXP LTR
Fixed regressors: C
Number of models evaluated: 16
Selected Model: ARDL(1, 0, 1, 1, 0)

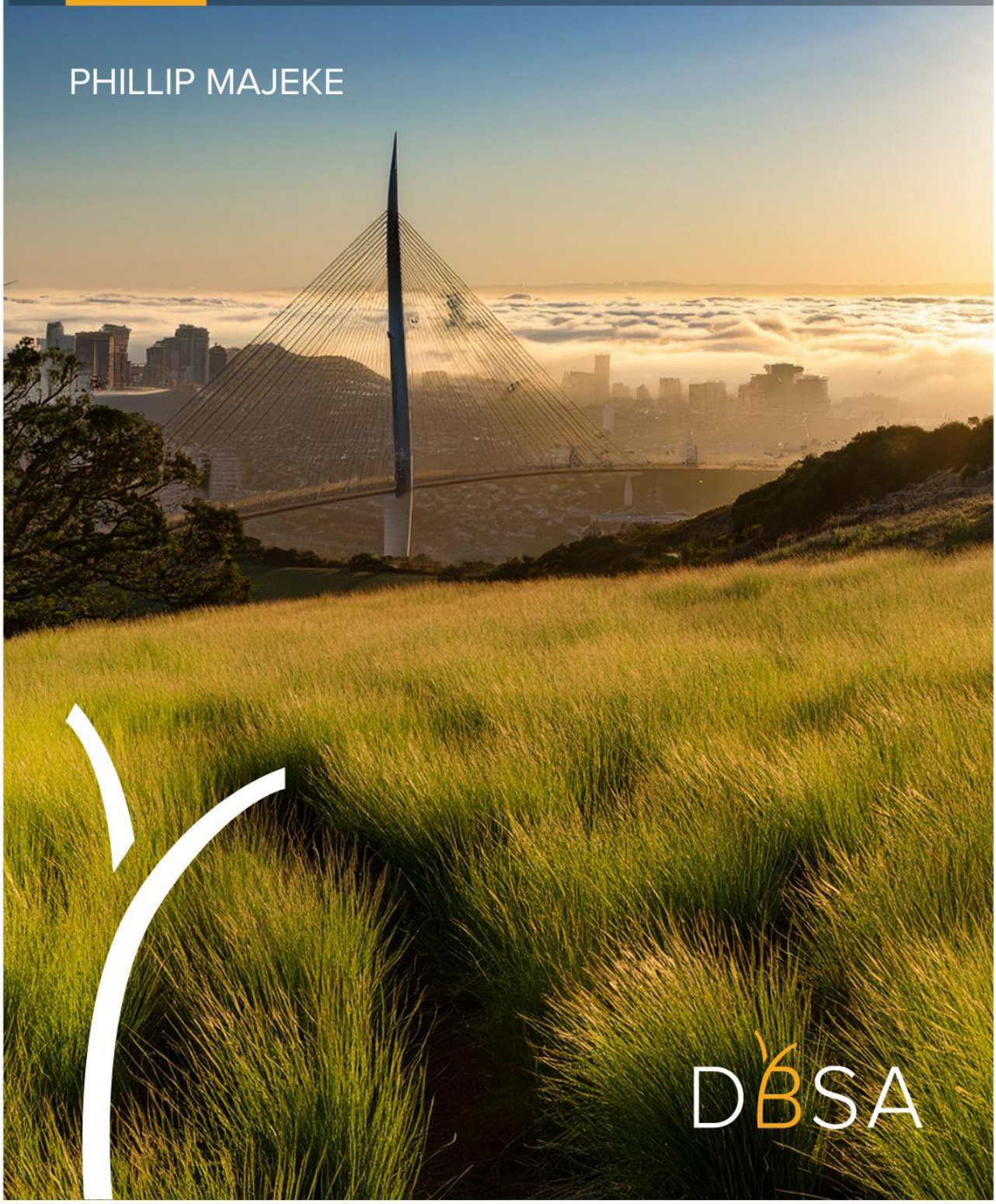
Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LGDP(-1)	0.719894	0.126953	5.670558	0.0000
LGFCF	0.033067	0.009961	3.319741	0.0034
LGOVEXP	0.184313	0.072982	2.525459	0.0201
LGOVEXP(-1)	-0.171052	0.043203	-3.959271	0.0008
LHCEXP	0.625054	0.054970	11.37092	0.0000
LHCEXP(-1)	-0.615416	0.108375	-5.678572	0.0000
LTR	0.031138	0.013382	2.326843	0.0306
C	3.083994	0.747727	4.124491	0.0005

R-squared	0.999458	Mean dependent var	15.10250
Adjusted R-squared	0.999268	S.D. dependent var	0.213512
S.E. of regression	0.005777	Akaike info criterion	-7.234961
Sum squared resid	0.000667	Schwarz criterion	-6.854331
Log likelihood	109.2894	Hannan-Quinn criter.	-7.118598
F-statistic	5266.132	Durbin-Watson stat	2.327659
Prob(F-statistic)	0.000000		

*Note: p-values and any subsequent tests do not account for model selection.

BUILDING CLIMATE RESILIENT
AND SUSTAINABLE SANITATION INFRASTRUCTURE THROUGH INNOVATIVE TECHNOLOGIES TOWARDS A CIRCULAR ECONOMY

PHILLIP MAJEKE



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BUILDING CLIMATE RESILIENT AND SUSTAINABLE SANITATION INFRASTRUCTURE THROUGH INNOVATIVE TECHNOLOGIES TOWARDS A CIRCULAR ECONOMY

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ABSTRACT

It is becoming increasingly recognised that poorly managed sanitation and wastewater systems are not only a significant contributor to greenhouse gas emissions (GHGs), but climate change also poses a serious threat to existing sanitation infrastructure and the public health progress made over the years. Households that have gained access to basic or safely managed sanitation services risk losing them during extreme climate-related disasters such as floods, droughts, and rising temperatures. This vulnerability will continue to prevail unless there is a shift towards emphasising that the design, selection, and implementation of sanitation systems must incorporate considerations for mitigating potential risks. There is an urgent need to research, develop, and demonstrate innovative sanitation technologies that are climate-resilient, environmentally sustainable, and promote circular economy principles within the sanitation value chain. Recognising this, the Water Research Commission (WRC) has prioritised research and innovation linking climate change and sanitation through the South African Sanitation Enterprise Programme (SASTEP). Through SASTEP, the WRC is actively evaluating and demonstrating cutting-edge sanitation technologies that are off-grid, climate-resilient, and support a circular economy by promoting water efficiency, wastewater reuse, and nutrient recovery from human waste. Most of these technologies are highly rated for climate resilience and are both mitigative and adaptive in addressing climate change challenges. These innovative solutions should be considered when selecting sanitation systems, particularly as part of long-term strategies that take future climatic projections into account. Doing so will ensure the establishment of sustainable, resilient sanitation systems that protect public health in the face of climate change.

Keywords: Sanitation, Sustainable, Circular Economy, Climate Change, Wastewater

INTRODUCTION

It is becoming increasingly recognised that poorly managed sanitation and wastewater systems are not only a big contributor to carbon emissions, but also that climate change threatens existing sanitation systems and public health progress made over the years. Households that have gained access to basic or safely managed sanitation services risk losing them during extreme climate related disasters. This will prevail until we consider and emphasize that the design, selection, and implementation of sanitation systems should consider mitigation of potential risks and shocks related to climate change. There is a need to research, develop and demonstrate innovative sanitation technologies that are climate resilient and promote circular principles within the sanitation value chain.

Climate change is a worldwide crisis. As temperatures and sea levels rise, people around the globe are increasingly experiencing heat waves, droughts, foods, cyclones, and wildfires. The effects of climate change are not equal, the poorest and most marginalised communities of our society feel the impact. Weather patterns are increasingly becoming less favourable and the frequency as well as severity of extreme events is increasing as temperatures are projected to continue rising and rainfall patterns are expected to shift. This will result in frequent flooding, heatwaves, droughts, storms, and sea level rise all of which have ripple effects on people and the environment.

Climate change impacts water availability which is going to have a negative impact on people, ecosystems, and the economy. At the same time, it exacerbates risks for water security which has negative effects on those sectors heavily dependent on water such as agriculture, electricity generation, mining, and industrial activities. Water is becoming increasingly polluted by human activities due to inadequate sanitation and open defecation practices. Also, many wastewater treatment plants are discharging sub-standard effluent as they are in critical condition (Green Drop Report, 2022)

According to the Intergovernmental Panel on Climate Change (IPCC, 2008), sanitation systems will be increasingly vulnerable if the design standards do not account for changing climate conditions and non-climate-resilient sanitation systems will expose the public to health hazards. In the event of severe flooding, damaged toilets and sanitation systems can spread waterborne disease across communities and settlements. In areas affected by drought, non-resilient sanitation systems contribute to water stress or can stop functioning, causing people to settle for open defecation. The impact of climate change will result in regression on the progress made over the years in the sanitation sector, hence the need for sanitation systems to be resilient to ensure universal access to safely managed sanitation for all as per the Sustainable Development Goals (SDGs).

The IPCC has stated that “the relationship between climate change mitigation measures and water is a reciprocal one” (IPCC, 2008). This relationship between climate change and water means that investing in climate resilient water and sanitation services is a vital part of solving the worldwide climate crisis. Supporting adaptation and climate resilient water and sanitation services makes sense from a financial point of view for both governments and users. It was indicated in COP27, recently held in Egypt, that for every dollar spent on water and sanitation services, resilience equates to 21 dollars in return and for every dollar spent on water flood, resilient upgrades equate to 62 dollars saved in flood restoration costs.

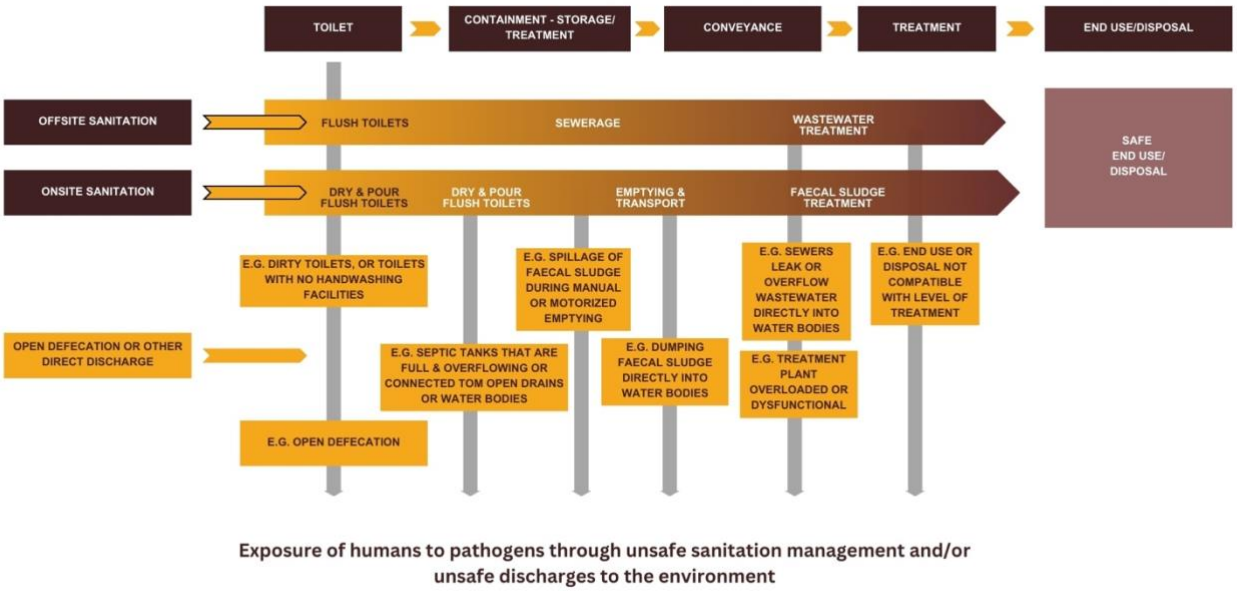

Figure 1: Excreta flow diagram showing examples of climate related hazardous events at each step of the sanitation service chain (adapted from Peal et al., 2014).

LITERATURE REVIEW

Impact of climate change on the sanitation value chain

The sanitation value chain comprises of collection/storage, transport/conveyance, treatment, and discharge/disposal or recycle/re-use as shown in Figure 1 above. Each area of the chain is highly vulnerable to the effects of climate change. Examples of some of the vulnerabilities are discussed briefly below:

Collection/storage

In areas that are not connected to sewer systems, on-site sanitation systems (septic tanks, conservancy tanks, pit toilets) are used and these systems are highly susceptible to adverse weather conditions and climate change as they can become flooded, overflow, and pollute the environment (USAID, 2015). Flooding may also result in the areas with on-site sanitation becoming isolated, as they may not be accessible during floods.

Transport/conveyance

In urban areas, sewage is conveyed through a system of pipes, pumps, and other associated infrastructure to a centralised wastewater treatment plant. These sewer systems may be damaged by extreme climatic events and cause uncontrolled discharge of raw wastewater into water resources (DEFRA, 2012), which can lead to pollution of the water resources (Howard et al., 2016). This was experienced in eThekwini Municipality during the floods in April 2022 where sanitation infrastructure was damaged.

Overflow of wastewater discharge onto streets or open ground poses a health risk to people and animals (DWS, 2016; EPA, 2004). Extended periods without any rainfall cause the degradation of sewers and the resulting accumulation of solid waste sediments can cause blockage which can result in backflow of raw sewage.

Treatment
Wastewater treatment plants are mostly located on low-lying areas as sewer systems rely on gravity, however this makes them vulnerable during flooding or sea-level rise. Declining annual rainfall or drought leads to the unavailability of water required to flush adequately and accompanying higher temperatures can have an impact on how sewage systems operate. Every extreme climate event (flooding or drought) affects the influent water quality of the wastewater treatment plants and that negatively impacts the operating efficiency and treatment ability of the plants (Howard et al., 2016).

Discharge/disposal
Flooding and drought affect the water quality of the receiving water bodies as the quality of the effluent is dependent on the volume of effluent discharge in the water resources (Miller & Hutchins, 2017). Drought has been observed to reduce the capacity of surface water to dilute, attenuate and remove pollution (DWA, 2013).

ClimateFirst Framework for rating overall resilience of sanitation technologies

The University of Technology Sydney's Institute for Sustainable Futures (UTS-ISF) developed ClimateFirst to provide guidance on assessing how the design features of sanitation systems can reduce the risks of failure during climate related hazardous events. The design features in ClimateFirst are based on a literature review of the latest thinking in resilient technological design across sanitation and other sectors and the opinions of sanitation experts. The development of the framework was supported by the Bill and Melinda Gates Foundation (BMGF). According to UTS-ISF, climate resilient sanitation service delivery includes institutional, technological, governance, service, financial, and social aspects. As such, ClimateFirst is not a complete guide to developing climate-resilient sanitation. It, however, should be considered as a resource focused on technologies and to be used as part of a wider shift towards resilient sanitation for all. Through use of ClimateFirst, sanitation designers and implementers can be equipped to rate overall climate resilience of a sanitation technology and select the best technology for the scenario at hand. The framework has 25 design features that are grouped into six categories as follows (See figure 2 also):

A. Avoiding exposure to hazards
Design features that reduce the likelihood that critical components and processes of the sanitation technology become directly exposed to a climate hazard.

B. Withstanding exposure to hazards
Design features that enable the sanitation technology to continue functioning "as normal" (i.e. no changes in hardware or operations) even when exposed to climate hazards.

C. Enabling flexibility
Design features that enable the adaptation or reconfiguration of a sanitation technology's hardware components or that enable changes to a sanitation technology's processes or operations so that the sanitation technology can continue providing services when exposed to climate hazards.

D. Containing failures
Design features that enable a sanitation technology to continue providing services (albeit potentially degraded) that meet user needs despite damage caused by climate hazards.

E. Limiting consequences of complete failure
Design features that minimise the negative consequences of a sanitation technology failing due to a climate hazard.

F. Providing benefits beyond resilience
Design features that enable the sanitation technology to provide other benefits to people or to other systems that aid in broader community or system resilience.

Category	Resilience design feature
A. **Avoiding exposure to hazards**	1. Raising
	2. Burying
	3. Portability
	4. No/low inputs
B. **Withstanding exposure to hazards**	5. Armouring and strengthening
	6. Oversizing
	7. Shapes that distribute pressure
	8. Circumvention
	9. Sealing and Barriers
C. **Enabling flexibility**	10. Adaptability
	11. Modular design
	12. Platform design
	13. Redundancy and diversity
	14. Signaling
D. **Containing failures**	15. Frangibility
	16. Fail-operational
	17. Decentralisation
E. **Limiting consequences of complete failure**	18. Safe disposal
	19. Reusable materials
	20. Fail-silence
	21. Repair speed
	22. Accessibility for rapid flaw detection and repair
F. **Providing benefits beyond sanitation technology resilience**	23. Reciprocity
	24. Hybridising
	25. Transformative capacity

Figure 2: ClimateFirst Framework resilience design features.
Source: UTS-ISF

RESEARCH METHODOLOGY AND METHOD

The Water Research Commission has prioritized research and innovation that links climate change and sanitation through the South African Sanitation Enterprise Programme (SASTEP). Through SASTEP, the WRC is evaluating and demonstrating non-sewered sanitation (NSS) technologies that are off grid and promote a circular economy within the sanitation value chain through water efficiency, water reuse and nutrients recovery from human waste. The technologies are described below:

Clear

The Clear NSS is a closed loop recycling and off-the-grid flushing toilet system. The system that treats wastewater and kills pathogens by means of a natural biological process, without the need for sewer connections, continuous water, or electrical mains supply with the uptake of the solar option. The waste stream from the toilet is initially stored in a black water collection tank. The tank provides residence time for the wastewater to equalize. The tank inventory is then pumped to the treatment section of the system where it is first treated to remove suspended solids and then it undergoes anoxic and aerobic biological treatment to remove organic and nitrogen, respectively. A special aerobic media is placed in the aerobic reactor and proprietary bacteria, specifically developed for treating wastewater is attached on the media as a biofilm. This biofilm can effectively biodegrade the organic pollutants and reduce its concentration. The treated stream is then passed through the membrane biological reactor (MBR). The MBR membranes serve as microbial barriers that can capture most of the biomass for recirculation inside the bioreactor. The MBR has exceptionally good solids/liquid separation effects and produces water that can either be reused for toilet flushing or discharged into downstream sewer directly or be reused as irrigation water. The water is dozed with ozone to further treat it and ensure it is pathogen free.

Schematic Flow

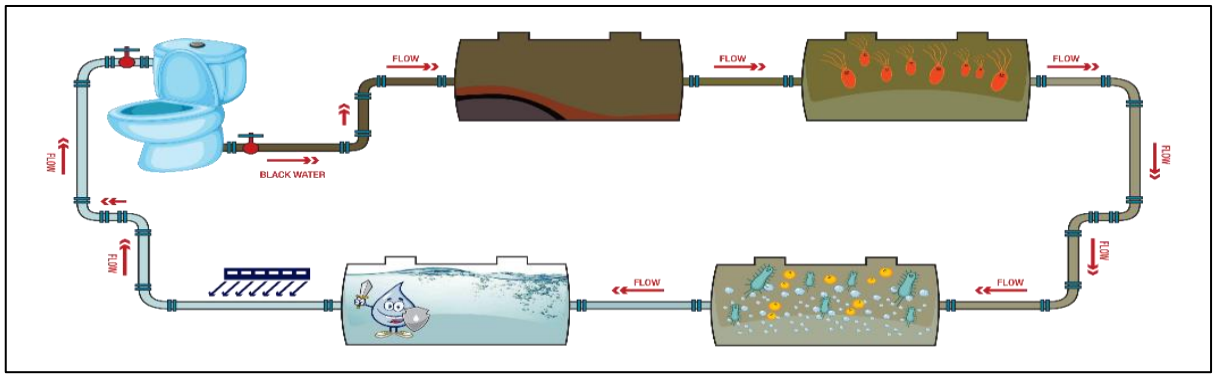

Figure 3: Schematic flow diagram of Clear NSS.
Source: American National Standards Institute

NEWgenerator

The NEWgenerator is a modular off-grid sewage treatment system that has been developed by the University of South Florida (USF). It treats sewage using an anaerobic membrane bioreactor, nutrient capture system, and electro-chlorination to produce treated water, biogas, and liquid fertilizer. Treated water can be recycled for toilet flushing to reduce the external

water demands. It is supplied with a solar system to provide all power required for the off grid running of the system.

Schematic flow

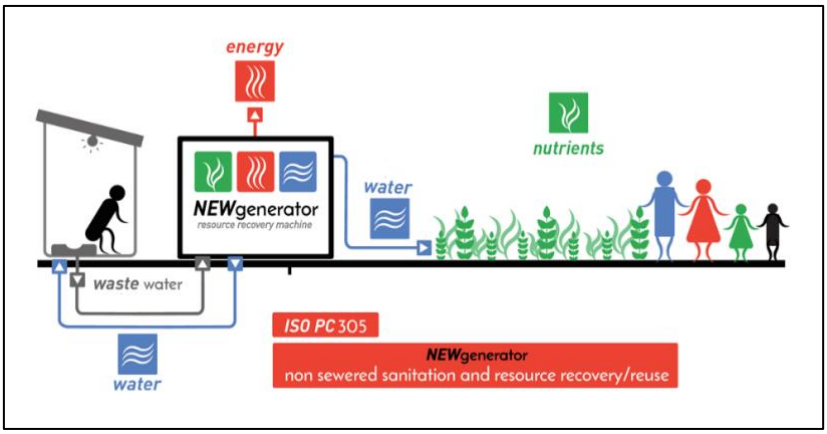

Figure 4: NEWgenerator schematic flow diagram.
Source: Wec Projects

Aquonic

Aquonic system is an onsite sewage treatment technology which treats grey and blackwater to a reusable quality for toilet flushing and/or irrigation utilizing biological and electrochemical processes. It is modular, an ideal solution to retrofit existing septic tank to improve overflow water quality output. It uses low energy and can be installed above ground or underground and it is suitable for use in public and private sector markets.

Schematic flow

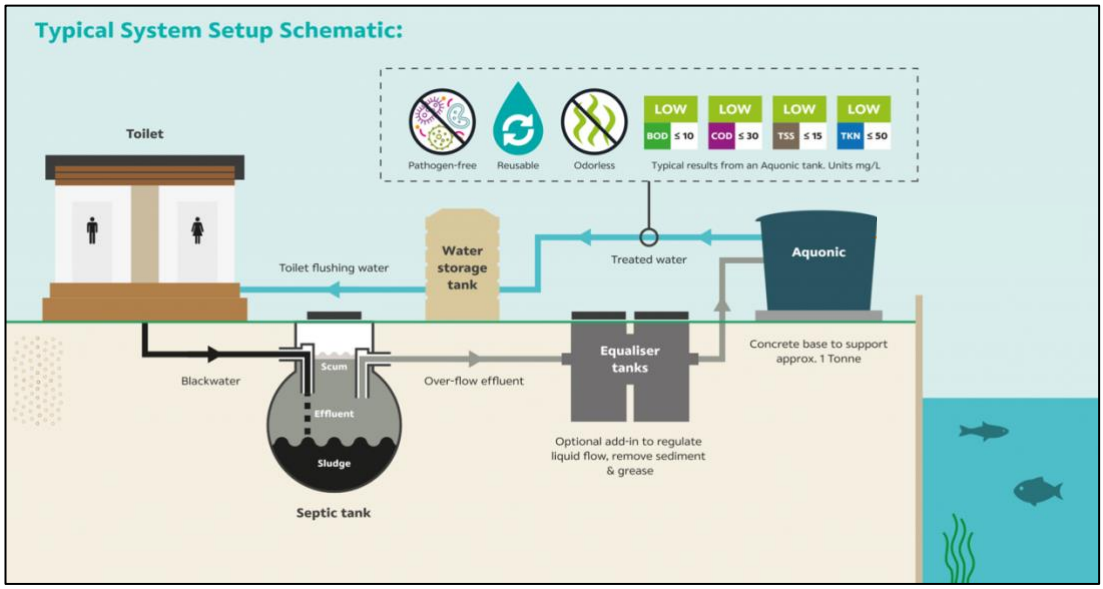

Figure 5: Aquonic schematic flow diagram.
Source: Prana Water and Sanitation

Dewdrop

The Dewdrop is a decentralized ecological wastewater treatment system with a modular design that provides convenient harvesting and reuse of domestic greywater. It can recycle up to 250L of greywater per day to produce safe, odour free non potable water for toilet flushing, car washing and garden watering. The system consists of anaerobic baffled reactor (ABR), planted gravel filter, tree filter and biochar filter for polishing of the final effluent.

Schematic Flow

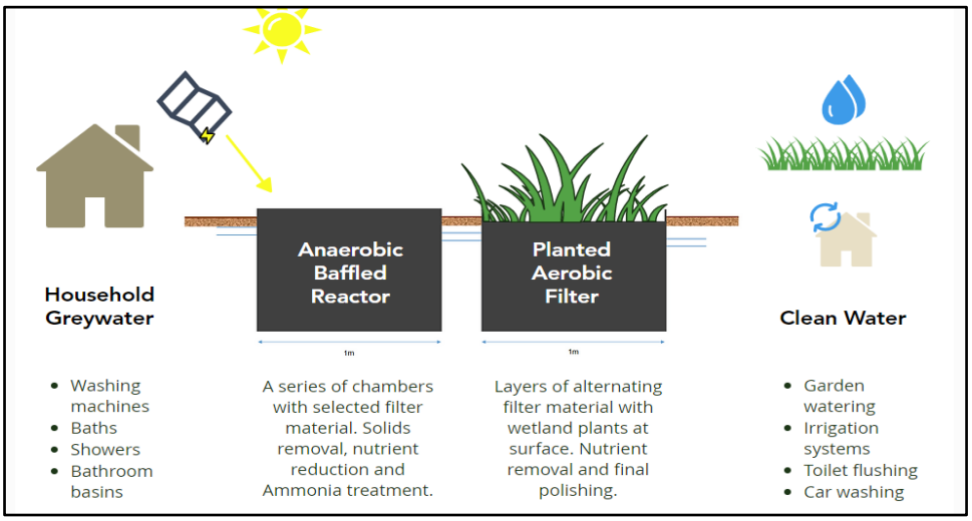

Figure 6: Dewdrop schematic flow diagram
Source: Wader Technologies

The above-described technologies were assessed for climate resilience using the ClimateFirst framework, which is a climate framework for improving resilience of sanitation technologies. ClimateFirst was developed by ISF-UTS funded by BMGF. The framework offers a process to consider how climate-related hazards can affect a sanitation technology and how the risks of these hazards can be reduced through technology design by incorporating climate resilient design features (ISF-UTS, 2023).

RESEARCH RESULTS

The detailed results of the ClimateFirst resilience framework for each of the NSS technologies are shown in Table 1 below:

Table 7: Overall climate resilience rating for non-sewered sanitation technologies

Category	Resilience design feature	Clear	NEWgen	Aquonic	Dewdrop
A. Avoiding exposure to hazards	1. Raising	Y	Y	Y	Y
	2. Burying	Y	Y	Y	Y
	3. Portability	N	N	N	N
	4. No/low inputs	Y	Y	Y	Y
B. Withstanding exposure to hazards	5. Armoring and strengthening	Y	Y	Y	Y
	6. Oversizing	Y	Y	Y	Y
	7. Shapes that distribute pressure				
	8. Circumvention	N	N	N	N
	9. Sealing and Barriers	Y	Y	Y	Y
C. Enabling flexibility	10. Adaptability	Y	Y	Y	Y
	11. Modular design	Y	Y	Y	N
	12. Platform design	Y	Y	Y	Y
	13. Redundancy and diversity	Y	Y	Y	Y
	14. Signaling	Y	Y	Y	Y
D. Containing failures	15. Frangibility				
	16. Fail-operational				
	17. Decentralisation	Y	Y	Y	Y
E. Limiting consequences of complete failure	18. Safe disposal	Y	Y	Y	Y
	19. Reusable materials	Y	Y	Y	Y
	20. Fail-silence				
	21. Repair speed	Y	Y	Y	Y
	22. Accessibility for rapid flaw detection and repair	Y	Y	Y	Y
F. Providing benefits beyond sanitation technology resilience	23. Reciprocity	Y	Y	Y	Y
	24. Hybridising	N	Y	N	N
	25. Transformative capacity	N	Y	N	N
Overall Resilience Rating		High (17/25)	High (19/25)	High (17/25)	High (16/25)

NB: Y - Yes and N – No

Source: Author's Work

Clear and Aquonic systems

Both systems have the same overall rating and resilient design features both scoring 17 out of 25 resilient design features. These systems are considered to be avoiding exposure to hazards (A), withstanding exposure to hazards (B), Enabling flexibility (C) and limiting consequences of complete failure (E) due to each having scored at least 75% of these categories of resilient design features. Both systems scored 33% in the resilient design category of containing failures (D) and providing benefits beyond sanitation technology resilience (F).

NEWgen

The NEWgen system had the highest overall rating and resilient design features scoring 19 out of 25 resilient design features. The system is considered to be avoiding exposure to hazards (A), withstanding exposure to hazards (B), Enabling flexibility (C), limiting consequences of complete failure (E), and providing benefits beyond sanitation technology resilience (F) due to the NEWgen having scored at least 66% of these categories of resilient design features. The system scored 33% in the resilient design category of containing failures (D).

Dewdrop

The Dewdrop system had a scoring of 16 out of 25 resilient design features. The systems are considered to be avoiding exposure to hazards (A), withstanding exposure to hazards (B), Enabling flexibility (C) and limiting consequences of complete failure (E) due to each having scored at least 75% of these categories of resilient design features. The system scored 33% in the resilient design category of containing failures (D) and providing benefits beyond sanitation technology resilience (F).

DISCUSSION

Climate Resilience Rating of NSS

The NSS technologies being demonstrated by WRC had 64 - 76% (16-19 out of 25) climate resilient design features in the climate resilient framework developed by UTS. Each system had at least one resilient design feature under all the 6 climate resilience design categories and thus all the technologies were rated high in terms of overall resilience. The Clear and Aquonic systems had the same scoring of 17 out of 25 for resilient design features whilst Newgen and Dewdrop scored 19 out of 25 and 16 out of 25, respectively. All the systems scored 33% in the resilient design category of containing structures which should be the areas of optimization and improvements in the future by designers and implementers.

Willingness of stakeholders

SASTEP has partnered with municipalities and the Department of Basic Education (DBE) to demonstrate new sanitation technologies, recognizing them as key early adopters. Currently, SASTEP is highlighting NSS technologies in 11 schools and 3 municipal sites. Additionally, the Department of Human Settlements has been engaged to update the design guidelines to include NSS as an option for sanitation provision. To date, DBE through its implementing

agent, has procured the 48 NSS system for schools in the Eastern Cape, Kwa-Zulu Natal and Limpopo indicating their willingness to adopt these NSS.

Improvements to previous prototypes

The NSS systems has offered the following improvements from previous prototypes:

Climate resilience: All the technologies scored high on the ClimateFirst Framework for resilience.

Water efficiency: The systems are designed to be off-grid and reuse treated water for flushing, reducing reliance on external water sources.

Energy efficiency: All the NSS systems have solar options.

Integration of tools

The ClimateFirst Framework tool is used to assess the climate resilience of these sanitation technologies, though this should be harmonised with other existing tools for various aspects like design, implementation, and cost analysis, etc.

Integration with existing/traditional sanitation systems

The focus of SASTEP is on NSS technologies. These are designed for areas without existing sewer infrastructure. Integration with traditional sewer systems might not be a primary goal. However, these NSS technologies could potentially serve as alternatives in areas where traditional systems are failing or not feasible.

Addressing odor issues

NSS technologies use biological treatment processes that efficiently break down waste, thereby reducing the production of odour-causing compounds and minimising sludge accumulation, which are common issues in conventional sanitation systems. Furthermore, many of the demonstrated NSS units have been installed near users, and surveys indicate that users themselves report no odour from these systems.

Funding source for operation and maintenance

SASTEP is promoting the procurement of NSS technologies with integrated Operation and Maintenance (O&M) plans included upfront. This approach ensures that the capital expenditure (CapEx) also covers the costs of O&M through a Service Level Agreement (SLA) for a specified period. By doing so, the long-term sustainability and functionality of the sanitation systems are secured, reducing the risk of system failures, and ensuring continuous, effective operation. For schools, the cost is borne by the Department of Basic Education (DBE), while for informal settlements, the municipalities bear the cost.

CONCLUSION

WRC is demonstrating NSS technologies which have a high-rating for-climate resilience and these technologies address both climate adaptation and mitigation pathways simultaneously by being water or energy efficient, reducing greenhouse gas emissions and being off-grid.

These technologies could have at least 64% of the resilient design features embedded into their designs and be considered when selecting sanitation systems that consider future climatic projections to ensure sustainable sanitation systems in the face of climate change. NSS systems improve upon previous prototypes by emphasising climate resilience, water efficiency through off-grid design and water reuse, and energy efficiency with solar options. They mitigate odour issues through biological processes and include upfront O&M plans funded by respective stakeholders, ensuring long-term sustainability.

RECOMMENDATIONS

It is especially important that the selection of appropriate sanitation technologies also be based on screening their vulnerability and adaptability to different climate scenarios apart from technical, financial, economic, social, and environmental considerations. The selected sanitation technologies should have a high-rating for-climate resilience and high adaptability to climate change. Existing infrastructure and technologies should be assessed for climate change resilience and where feasible, be modified to reduce the adverse impacts of climate related events. Further efforts should focus on integrating NSS systems into existing sanitation frameworks where feasible and ensuring comprehensive O&M plans are included from the outset to sustain functionality and reduce operational risks.

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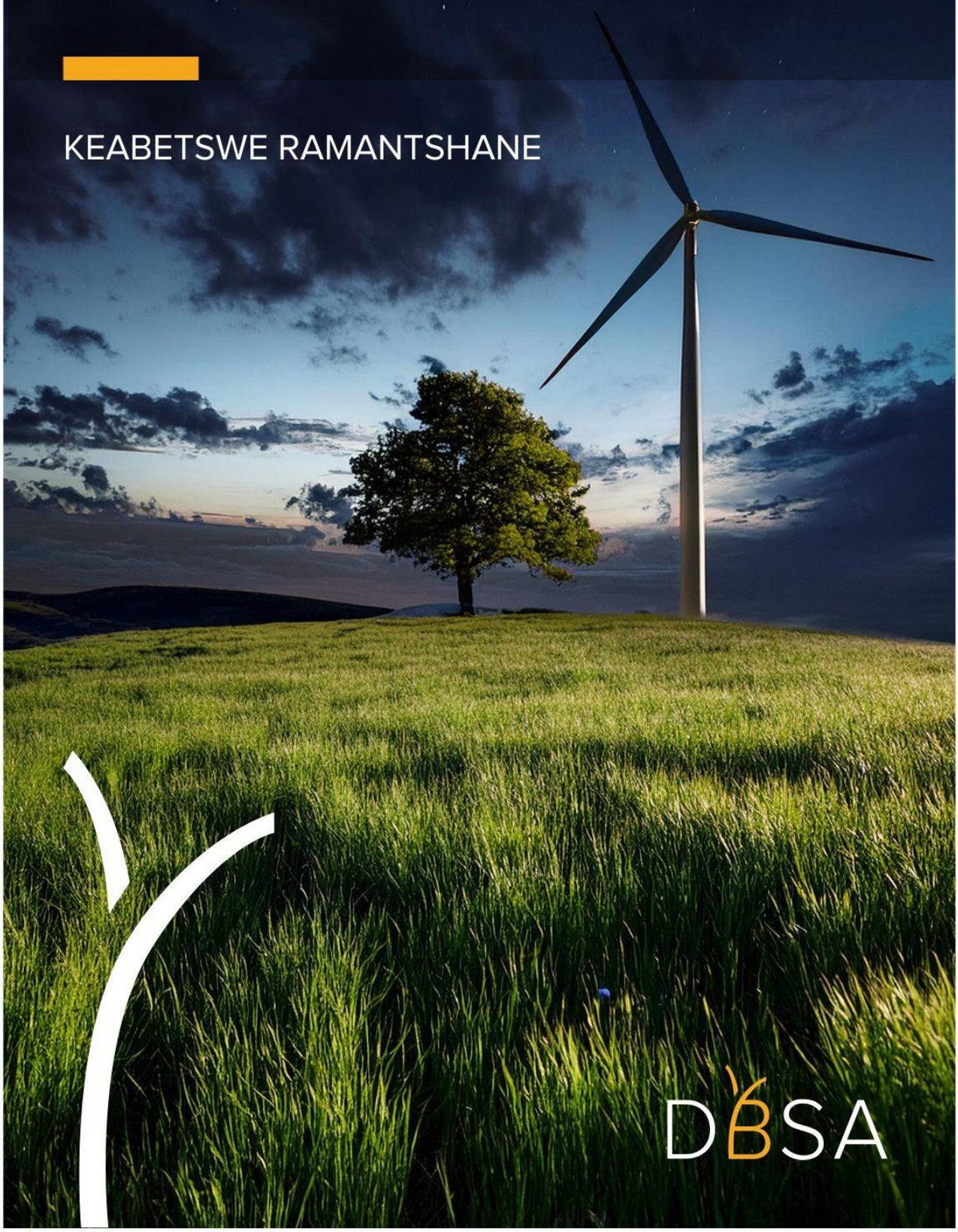
AN INFRASTRUCTURE FUNDING MODEL(IFM) FOR PROJECT DELIVERY IN NON-URBAN / RURAL AREAS OF SOUTH AFRICA

KEABETSWE RAMANTSHANE



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AN INFRASTRUCTURE FUNDING MODEL(IFM) FOR PROJECT DELIVERY IN NON-URBAN/RURAL AREAS OF SOUTH AFRICA

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ABSTRACT

Rapid urbanisation has been identified as a key factor contributing to rising urban congestion and poverty levels. The global goals of eliminating poverty and hunger are unlikely to be achieved if the trend of rural-urban migration continues unabated. One of the primary causes of this migration is the lack of adequate infrastructure in rural areas. Literature consistently highlights the essential role of infrastructure in fostering economic growth and improving citizens' welfare. Therefore, it is critical for governments to prioritize rural infrastructure development to curb rapid urbanisation. Developed countries have successfully implemented strategies to address this issue. For example, the UK's co-lending model focuses on rural development lending, while China uses redistributive tools like tax systems and lump sum transfers to enhance rural infrastructure. However, many developing countries, including South Africa, continue to prioritize infrastructure spending in urban areas, neglecting rural communities and worsening the disparity. This study adopts a mixed methods approach, targeting three provinces for comprehensive data collection. It incorporates the resource allocation theory and situational awareness theory to analyse infrastructure funding mechanisms. The qualitative component includes 10 interviews per province, while the quantitative segment involves distributing 60 surveys at local, provincial, and district levels. Regression analysis will be applied to assess the extent to which Infrastructure Funding Models (IFM) are utilized and to develop a more effective model for equitable infrastructure funding. The aim is to create a resourceful funding framework that addresses rural development needs and ultimately mitigates the adverse effects of rapid urbanisation

Keywords: Infrastructure Development, Rural Development, Economic Growth, Funding Model, Project Delivery

INTRODUCTION

The absence of infrastructure in South Africa's rural areas is not only glaring but has worsened the living conditions in these areas leading to unprecedented migration to the urban centres. This is despite the policy hue of the present national government to invest significantly in the rural areas. Rural poverty is linked to the exposure of households to economic vulnerability and welfare which is impacted by unfavorable resource allocation (Mokoena, Rachidi and Ngwakwe, 2020). Scarcity of studies seeking to appraise the extant infrastructure funding model for infrastructure delivery financing for rural areas has been observed, especially within the South African context. Previous studies have explored structures for funding. The studies have not considered a comprehensive model to implement and support financing techniques for the delivery of infrastructure in the Non-Urban Rural and Borderline (NRBs). This is the gap which this study seeks to bridge. As such, this study will seek to develop and validate an appropriate infrastructure funding model for engendering improved infrastructure spending in rural South Africa.

BACKGROUND

Flyvberg, Garbuio and Lovallo (2009), observed that infrastructure spending constitutes the largest share of the world's Gross Domestic Product (GDP) with 22 trillion dollars in projected investment by 2019 in emerging economies alone. Infrastructure development is a major contributor of economic growth for many countries (Wong, Wang, Luo, Zhang, and Rozelle, 2017). The provision of infrastructure is focused on large cities and towns in most parts of the world. South Africa is replete with developed cities and non-urban areas which are either underdeveloped or undeveloped. This poses a challenge to the country and constitutes a strain on cities due to population migration. Scholarly research reveals a lack of sustained rural infrastructure investments in developing countries as such that this has set challenges for economic development and growth in rural economy for the residents and investors at large (Flyvberg et.al., 2009).

This research contributes to the school of thought that emphasises infrastructure development as an enabler of socio-economic development and economic growth for non-urban and rural areas (Development Bank of Southern Africa, 2012). Where development partly exists, which hardly occurs in rural areas, there tends to be inadequate infrastructure thus implying a lack of infrastructure funding. The infrastructure funding model (IFM) has a set standard of methods to finance development projects which are successfully implemented by the public and private sectors. Unfortunately, not all projects have a successful outcome, others are incomplete or have dismally failed due to challenges that arise (Flyvberg et. al., 2009). Similarly in non-urban or rural areas there are problems of the same nature. Most of these challenges are related to financial repercussions such as the allocation of minimal budget (Flyvberg et. al., 2009). The majority of infrastructure failures and challenges encountered in rural areas, non-urban areas and the borderline environment relate to lack of financial commitment or investment.

KNOWLEDGE GAP OF CONFERENCE PAPER

The focus of this study is on the infrastructure funding models in use for infrastructure development in Non-urban/Rural and Borderline (NRB) areas and their effectiveness during implementation. The solution seeks to address the problem being studied, namely the absence of an effective infrastructure funding model (IFM) for facilitating infrastructure development in NRB areas. The South African government has a challenging exercise of creating sustainable economic growth throughout the country through infrastructure development but more specifically in the NRB environment. The Medium-Term Expenditure Framework (MTEF) has illustrated budgetary requirements for urban cities over the years however the NRB areas have not benefitted much from this framework. Hence, this study aims to develop a beneficial infrastructure funding model for both cities and NRB areas which will seek to resolve challenges pertaining to lack of infrastructure development and economic growth.

AIM OF CONFERENCE PAPER

The goal of this research is to develop an effective and efficient infrastructure funding model (IFM) for the delivery of infrastructure in South African NRB areas with the following as the secondary objectives:

1. To appraise the extant of infrastructure funding models available for infrastructure delivery in South Africa-both urban, rural, and non-urban areas;
2. To determine the effectiveness of the funding models for infrastructure delivery financing in rural, NRB areas;
3. To identify the factors influencing the effectiveness or otherwise of these models as they pertain to infrastructure delivery in rural non-urban and borderline areas of South Africa;
4. To model the influence of these factors on the effectiveness of the extant funding models in the delivery of infrastructure in NRB areas;
5. To develop and validate a suitable funding model for infrastructure delivery in rural non-urban borderline areas of South Africa.

The next below section addresses existing literature on rural infrastructure, municipal infrastructure, financial resource allocation, economic growth, and the revenue index model.

LITERATURE REVIEW

The Relationship between Rural Infrastructure and Economic Growth

There is a philosophy that illustrates infrastructure as the key element of economic growth which in turn attracts investors (Van de Walle, 2002). O'Brien and Pike (2015) state that the critical importance of infrastructure to productivity and output growth has been accentuated in the context of globalization, technological advances and shifting social demands. Agenor (2010) recognises the relationship between allocation of public expenditure and economic growth which is embodied by the economic theory (Mokoena, Rachidi and Ngwakwe, 2020).

Furthermore, (Agenor, 2010) asserts that where there is an increase in infrastructure development, there are patterns of potential economic growth.

NRB areas face a challenge to retain human resources for purposes of stimulating economic growth, this being attributable to a lack of infrastructure related resources. According to Zulu and Mubangizi (2014), high economic growth rates can be achieved through infrastructure development. In addition, this will enhance local economic development to create robust and inclusive local economies that exploit local opportunities, address local needs, and contribute to national developmental objectives.

Municipal Infrastructure Development

Rural infrastructure development is dependent on the successful implementation of an appropriate infrastructure funding model. Upon municipalities' failure to have an action plan for infrastructure development, NRB areas will deteriorate further resulting in no infrastructural growth. There is an estimated number of 257 municipalities in all provinces of South Africa with each municipality having its own challenges. According to Van der Waldt (2014), "various agencies", such as the South African Local Government Association (SALGA), National Treasury (NT), the Department of Co-operative Governance and Traditional Affairs (CoGTA), as well as individual municipalities, "perform audits of their own infrastructure to determine the status of its existence". The viability of a municipality can be measured by its ability to raise revenue to pay for basic public services, one way of assessing the ability of municipalities is to compare the gap between expenditure needs and revenue-raising capacity (Bandyopadhyay, 2013; Mokoena et.al., 2020). According to CoGTA (2016) funding is received from national and provincial governments and then only distributed to the local municipalities. The funds supplement municipal revenue for the provision of free basic services to poor households, and for the funding of institutional capacity and support to weaker municipalities. The department distributes the funds from the grants based on their determination of the level of assistance the municipality needs CoGTA (2016).

The challenges identified from the need-capacity or fiscal gap causes a contraction in the growth of infrastructure and lack of viability for municipalities. Expenditure needs is the amount of money needed to provide minimum acceptable levels of public goods (water, electricity, refuse removal, roads, etc.), while revenue-raising capacity refers to revenues that the municipality can raise from its own sources (own revenues) when exerting a standard amount of effort. According to Ncube and Monnakgotla, (2018), a municipality's revenue-raising capacity depends on its fiscal capacity, which can be measured using many variables. These variables range from municipality tax and revenue base to its socio-economic framework and all other political and legal constraints that may prevent its full revenue potential being realised. The most vital component of a municipality is its fiscal capacity and economic base (Ncube and Monnakgotla, 2018). Municipalities are expected to raise their own revenue through a collection of taxes from services rendered, however this is currently not realistic with the NRB areas, due to lack of revenue from tax bases.

Also, Ostrom, Shroeder and Wynne, (2013) maintain that the concept of donor funding is seldom applied especially where they can have an influence on availability of capital investments in the rural areas. This lack of application is exercised more in the delivery of rural infrastructure in less developed countries (Ostrom et. al., 2013). In developing countries, rural

infrastructure is characterised by donor interventions, which considers how they can influence the incentive structures affecting the sustainability of capital investments (Ostrom et. al., 2013). According to Skerratt, (2010), funding can be derived from charitable trusts, subsidised subscriptions as well as pay-for-use projects for the purpose of rural infrastructure development. On the contrary, infrastructure development in cities is dependent on collectable taxes for continuous infrastructure development which is generated through the revenue index model illustrated in the section below.

Infrastructure Delivery Management System (IDMS) Framework

"The Infrastructure Delivery Management System (IDMS) is a government management system for planning, budgeting, procurement, delivery, maintenance, operation, monitoring and evaluation of infrastructure" (Treasury, 2012). Within the IDMS there are a number of inter-related systems with the objective of ensuring that the requirements illustrated by the Medium-Term Expenditure Framework (MTEF) are met in compliance with the relevant legislation (Treasury, 2012). The IDMS is linked to a number of systems with the sole purpose of ensuring that the infrastructure needs illustrated in the MTEF are met based on the budget per capita. The IDMS comprises of the following systems where each system manages its own risks, namely: an infrastructure planning system (IPS), an infrastructure gateway systems (IGS), a construction procurement system (CPS), a programme and project management system (PPMS), and an operations and maintenance system (OMS).

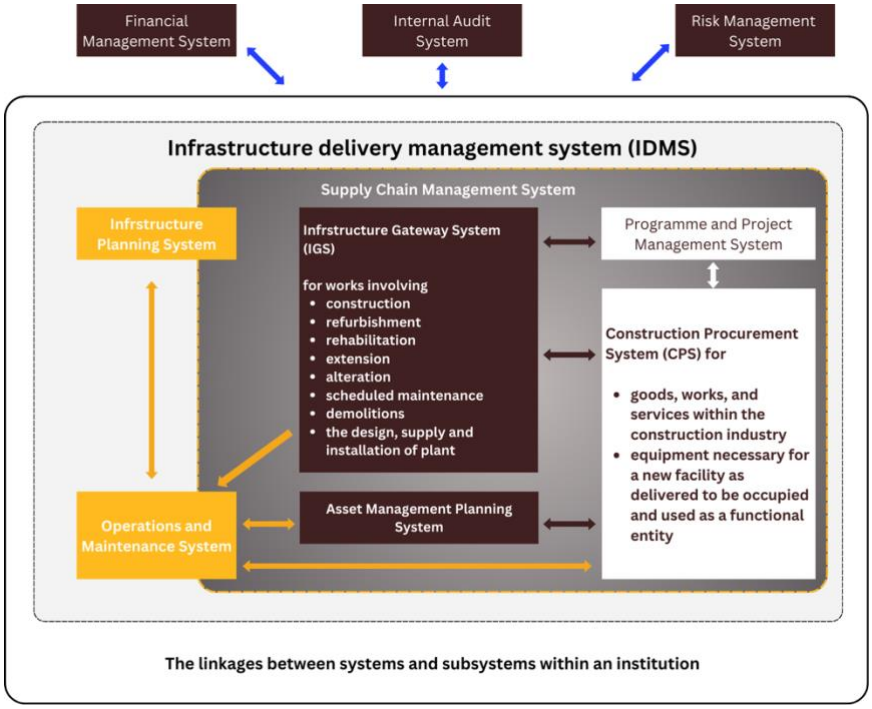

Figure 7: Infrastructure Delivery Management System (IDMS) – Treasury (2012)

Financial Resource Allocation for developed countries

Some researchers focus on the importance of infrastructure, particularly in road infrastructure to support the objective of agricultural output, economic growth, and poverty reduction (Van de Walle, 2002). Furthermore, to generate economic efficiency for the transport sector in the

United States the cost-benefit analysis and guide project selection and design by maximizing on the best models is used (Soleymani, Ravanshadnia and Montazer, 2021). Additionally, Siegel, (2005) denotes that changes may have led to improvements in the quantum of rural poverty rates however the region is still characterised by inequalities in assets and incomes. Wong et.al. (2013) and Mellor (2020) allude that the rapid growth of a small commercial farmers dominates agriculture, accelerates economic reform whilst encouraging the decline in rural poverty. In the United States a selection of investment projects in the rural roads sector, has the objective of poverty reduction and develops an operational approach in line with the public economics framework. As such, it is argued that the transport sector should be geared to maximise efficiency on a first-best model of the economy, where one aims for efficiency in production, and redistributive instruments such as the tax system and the lump-sum transfers are used to achieve the redistribution objective. Moreover, Siegel (2005) promotes the asset-based approach where household assets are considered as drivers of economic growth. Drivers of sustainable rural growth and poverty reduction is part of an ongoing effort by the Central American Environmentally and Socially Sustainable Development. Furthermore, Siegel (2005) states that government and donors lack understanding on the drivers of rural growth and poverty reduction hence there is minimal investments and prioritisation strategies.

Skerratt (2010) outlined the widespread acceptance in academic research and in policy statements and interventions of rural Scotland that the absence or presence of infrastructure and services in rural areas can lead to cycles of decline or resilience in these localities. It is also accepted that in remote areas, population sparsity leads to a higher unit cost for delivery of services and infrastructure. O'Brien and Pike (2015), follow solid persistence on government reform in England at the city/city-region or local level in return for further decentralised funding and powers, brokered by deal-making, from the Manchester (Devo-Manc) Model. Tomaney and McCarthy (2015) raise three fundamental issues; First, Greater Manchester is a distinct city-region based primarily on an urban geography, it has provided the basis for several joint economic development, transport, and public service arrangements on behalf of constituent local authorities across a functional economic area. On the contrary rural Scotland is not privileged to have such economies of scale, nor will all cities, city-region or other rural areas be in a similar position. Furthermore, cities and city regions facing relative decline with weaker economic potential have narrower tax bases and deeper social needs and face the prospect of being disadvantaged in such a system (Pike, Rodriguez-Pose, Tomaney, Torrisi and Tselios, 2012). There is a genuine risk that pursuing a Greater Manchester (Devo-Manc) model will not produce the desired outcomes in other areas that are envisaged by government (O'Brien and Pike, 2015).

Moreover, evidence on the economic effects of decentralized governance is mixed and inconclusive, and the interconnection between governance arrangements and economic and social outcomes is difficult to isolate (Tomaney, Pike, Torrisi, Tselios, Rodriguez-Pose,2011) and (Pike, Rodriguez-Pose, Tomaney, Torrisi, and Tselios,2012). Therefore, in determining a feasible infrastructure funding model for the rural areas it is critical to bear these factors for consideration. An alternative model by Acharya, and Sundaresan (2014) holds the view that the PPP programs were established to fund infrastructure projects (Zang, Hou, and Qian, 2020). This co-lending model was developed by Australia and is used by over 56 countries where it lends on commercial terms to both private and public sectors to bridge the financial gap for both sectors to fund privately financed initiatives (PFI) which indicates a potential opportunity for the development of rural areas.

Own Revenue Index Model

Ncube and Monnakgotla (2018), developed a model named the own-revenue index. It is generated from a ratio of own revenues to total revenues and according to the index, own revenue is the main source of income for over 70% of newly demarcated municipalities. Due to lack of generation of taxes and services in NRB areas, municipalities struggle to generate their own revenues. Dang (2013); Ncube and Monnakgotla (2018) illustrate that a system of taxation and public expenditure raises revenue and control over expenditure on various levels within government. While taxes and fees are known as traditional revenue generation instruments, other cash generation methods such as grants, bond-based finance, tax incentives or infrastructure levies are classified as the recent innovative financing vehicles (Squires, Javed, Trinh, 2021). With consideration of the per capita gross value added (GVA) index, this indicator measures the value of goods and services produced by a municipality over a given period (Ncube and Monnakgotla, 2018). Municipalities with a higher capita GVA have a larger revenue base and an inherent ability to pay taxes.

RESEARCH METHODOLOGY AND METHOD

This study adopts a pragmatist philosophical stance. Accordingly, a mixed methods research design is deployed for data collection and analysis. Paper-based and electronic surveys were distributed to the relevant personnel at different municipalities and the Non-urban, Rural and Borderline (NRB) communities across three (3) provinces to investigate the level of understanding on infrastructure funding models and its benefits to rural development. In addition, interviews were conducted considering the need to establish an enhanced view of people directly and indirectly affected by infrastructure challenges. A random selection of the current 257 municipalities across all nine provinces was conducted as part of the data collection and sampling process, where interviews are targeted to key informant officials. Once the data is collected from the municipalities through surveys, interviews were held with officials from the different municipal categories (Local, Provincial and District) to outline the problem and address the study. However, it is important to note that this study's scope is limited to three provinces (Gauteng, Limpopo, and Mpumalanga) and limited municipalities. As a result, the findings may not be fully generalisable to other provinces. Hence, future research could extend the scope to include other provinces and more municipalities, to enable broader comparative insights and greater generalisability of the results.

				SURVEY Matrix		
Interviews				Official Data		
10 Interviews conducted with local municipalities				Total Local Municipal data	Total Provincial Municipal data	Total District Municipal data
				SURVEYS		
GP	10			20	10	10
LIM	10			3	3	3
MP	10			**60**	**30**	**30**

Table 1: Survey & interview plan

Source: Author's Work

RESEARCH RESULTS

This section illustrates the highest and lowest resource allocation for each province with the focus on data collection from Gauteng, Limpopo, and Mpumalanga. This explored the thought process of the underlying factors that state that higher resource allocations are consistently distributed to urban municipalities while local/rural municipalities are exposed to a relentless infrastructure crisis due to lack of resources. Table 1 maps out the infrastructure need status based on the data demonstration discussed in the section below.

Province	Water/ Sanitation	Electricity	Roads/ Transportation	Healthcare Services	Telecommunication
GP	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Low**
MP	**High Priority**	**Moderate**	**High Priority**	**High Priority**	**Low**
LIM	**High Priority**	**Moderate**	**High Priority**	**High Priority**	**Low**

Table 8: Rural Infrastructure Status per Province
Source: Author's Work

The City of Johannesburg has the allocation of R9464674 for year 2017 and R9771313 for 2018 and the lowest grant allocation was to Midvaal with R138398 for the year 2017 and R166113 for the year 2018 respectively (Statistics SA, 2019). The City of Johannesburg Metropolitan municipality was recorded to have a population of 4434827 in year 2011 and increased to 4949347 in the year 2016 (Municipalities, 2019), on an area of 1644.98 km² radius (Census, 2011). The population growth rate was recorded to be 2.49% per annum from the year 2011 to the year 2016.

Furthermore, the year 2016 confirmed that basic infrastructure development in the asset class of sanitation with full connection to the sewerage system is at 88.6%, where weekly refuse removal is at 85.4% water supply specifically piped water for the benefit of households is at 60.3% and access to electricity of 90.9% in this area (Municipalities, 2019). The Midvaal local municipality was recorded to have a population of 95301 in the year 2011 and increased to 111612 in the year 2016 (Municipalities, 2019) on an area of 1722.47 km² radius (Census, 2011). The population growth rate was recorded to be 3.59% per annum from the year 2011 to the year 2016. Furthermore, the year 2016 confirmed that basic infrastructure development in the asset class of sanitation with full connection to the sewerage system is at 62.6%, where weekly refuse removals is at 82.9% water supply specifically piped water for the benefit of households is at 62% and access to electricity of 81.9% in this area (Municipalities, 2019).

Min			Median			Max		
Municipality	2017	2018	Municipality	2017	2018	Municipality	2017	2018
Midvaal LM	138 398	166 113	Merafong City LM	381 998	372 536	City of Tshwane MM	612 3596	646 7568
Lesedi LM	146 878	185267	Mogale City LM	441 376	625 292	Ekurhuleni MM	686 7925	727 4925
West Rand DM	242 918	252 906	Rand West LM	468 632	479 629	City of Johannesburg MM	946 4674	977 1313

Table 9: Gauteng – Municipal Grant allocation (Statistics SA, 2019

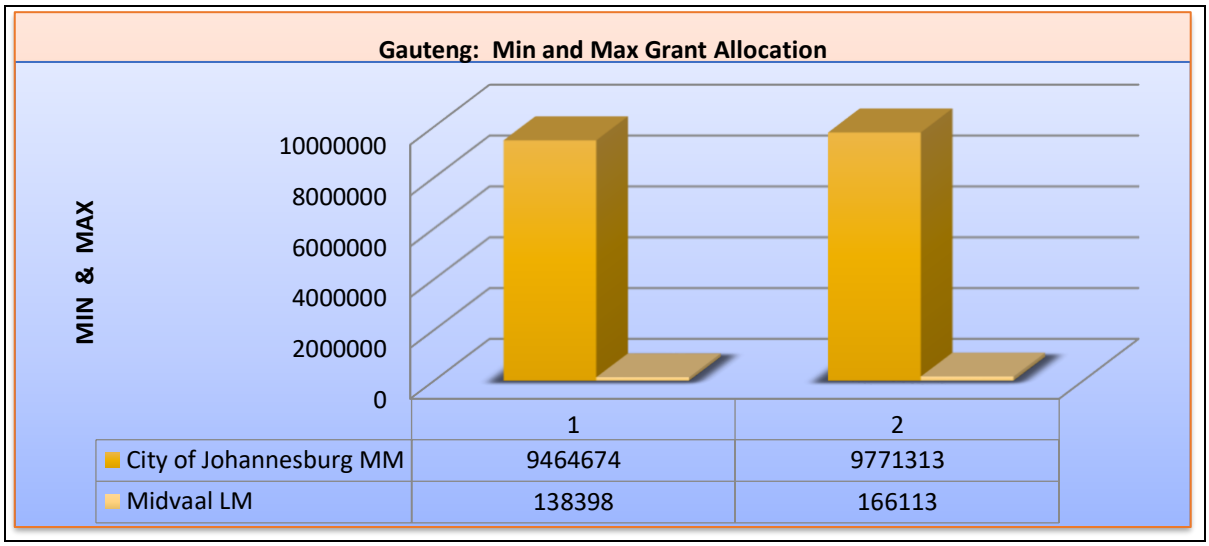

Figure 8: Gauteng Min and Max Grant Allocation (Statistics SA, 2019)

The Thabazimbi local municipality was recorded to have a population of 85234 in year 2011 and increased to 96232 in the year 2016 (Municipalities, 2019), on the area of 11190.14 km² radius (Census, 2011). The population growth rate was recorded to be 2.76% per annum from the year 2011 to the year 2016. Furthermore, the year 2016 confirmed that basic infrastructure development in the asset class of sanitation with full connection to the sewerage system is at 57.9%, where weekly refuse removal is at 41.7% water supply specifically piped water for the benefit of households is at 38% and access to electricity of 74.9% in this area (Municipalities, 2019).

Min			Median			Max		
Municipality	2017	2018	Municipality	2017	2018	Municipality	2017	2018
Thabazimbi LM	93240	73592	Blouberg LM	261623	256302	Sekhukhune DM	1072910	1251854
Waterberg DM	125360	121975	Greater Letaba LM	270846	316409	Vhembe DM	1304349	1360763
Ba-Phalaborwa LM	143068	176813	Elias Motsoaledi LM	282035	324064	Polokwane LM	1342039	1578024

Table 4: Limpopo – Municipal Grant allocation (Statistics SA, 2019)

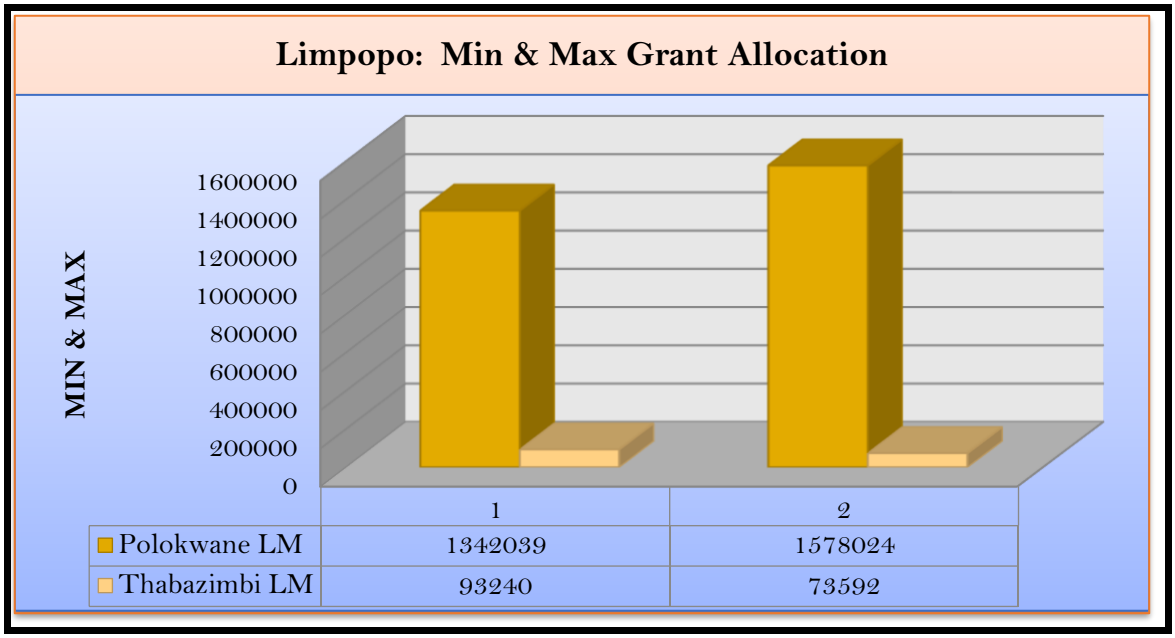

Figure 9: Limpopo Min and Max Grant Allocation (Statistics SA, 2019)

Bushbuckridge was allocated R1321757 for the year 2017 and R1207194 for the year 2018, with the lowest allocation of R88535 for the year 2017 and R112214 for the year 2018 for the Emakhazeni Municipality in Mpumalanga (Statistics SA, 2019). The Bushbuckridge local municipality was recorded to have a population of 538593 in year 2011 that increased to 546215 in the year 2016 (Municipalities, 2019), in the area of 10249.93 km² radius (Census, 2011). The population growth rate was recorded to be 0.32% per annum from the year 2011 to the year 2016. Furthermore, the year 2016 confirmed that basic infrastructure development in the asset class of sanitation with full connection to the sewerage system is at 6.2%, where weekly refuse removal is at 4.2% water supply specifically piped water for the benefit of households is at 7.4% and access to electricity of 96.5% in this area (Municipalities, 2019).

The Emakhazeni local municipality was recorded to have a population of 47216 in the year 2011 and increased to 48149 in the year 2016 (Municipalities, 2019) on the area of 4735.59 km² radius (Census, 2011). The population growth rate was estimated to be 0.94% per annum based on the year 2011 population data (South Africa Population, 2019) however Municipalities (2019) that recorded the population growth rate from the year 2011 to the year 2016 to have been at 0.44% per annum. Furthermore, the year 2016 confirmed that basic infrastructure development in the asset class of sanitation with full connection to the sewerage system is at 75.2%, where weekly refuse removals is at 56.3% water supply specifically piped water for the benefit of households is at 46.7% and access to electricity of 83.1% in this area (Municipalities, 2019). Additionally, these efforts of minimal infrastructure development have a direct and indirect contribution to the unemployment rate which was estimated to be 34.2% in the year 2016.

Table 10: Mpumalanga – Municipal Grant allocation (Statistics SA, 2019)

Min			Median			Max		
Municipality	2017	2018	Municipality	2017	2018	Municipality	2017	2018
Emakhazeni LM	88535	112214	Thaba Chweu LM	208628	221365	Nkomazi LM	828019	737111
Dipaleseng LM	95522	102063	Ehlanzeni DM	227283	238224	City of Mbombela LM	1131384	1219533
Victor Khanye LM	111507	114006	Mkhondo LM	250087	329104	Bushbuckridge LM	1321757	1207194

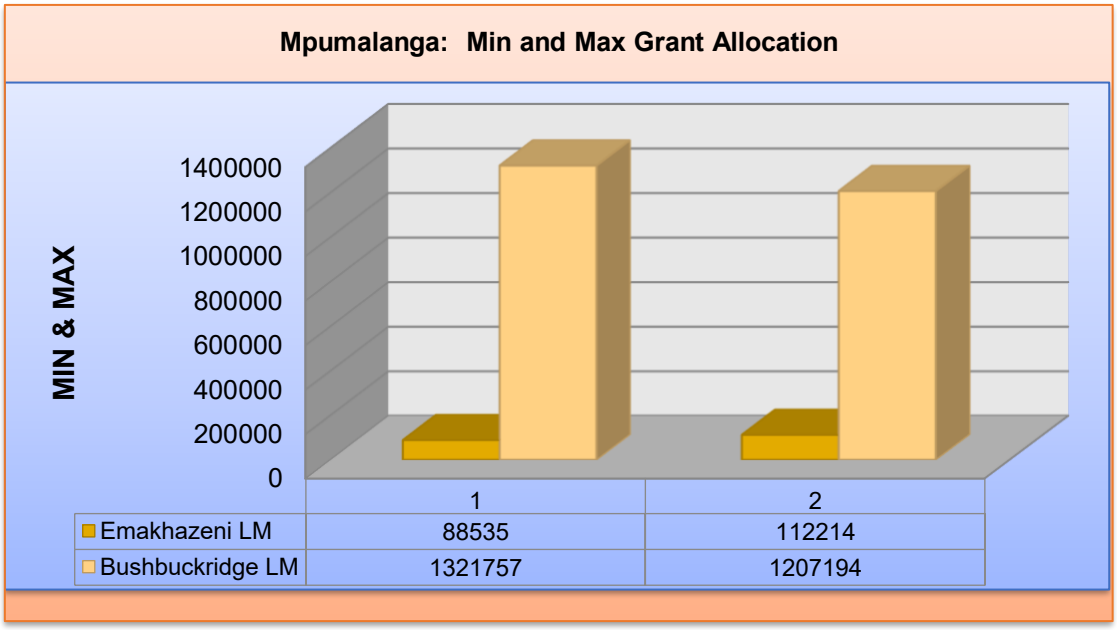

Figure 10: Mpumalanga min and max grant allocation (Statistics SA, 2019)

DISCUSSION

The above representation of Gauteng, Limpopo and Mpumalanga provides a comparison of grant allocation from lowest to highest municipalities and indicates that the municipalities that have received the highest grants are not in the NRBs. This illustration depicts the challenges raised in the research questions on resource distribution. Below are the proposed attributes which determine the asset classes to consider in developing the model algorithm.

Table 11: Equation Attributes

Province(P)	Local (L)
Non-Urban, Rural and Borderline (NRB)	Metro(M)
Population(P)	Electricity®
Water (w)	Sanitation (s)
Solid Waste (SW)	Borderline(B)
Urban(U)	Non-Urban (Nu)
District(D)	Rural®
t = time	r = rate

Source: Author's Work

Model A: Urban Allocation = $\boldsymbol{u = d^{n+1}m^{n+1}}$
Factor: Population growth rate = $\boldsymbol{P_t = P_0\,(1+r)^t}$

The below grant allocation model structures the allocation process on the basis of the regional prioritization model and attributes illustrated in the above table: Equation 1: Average Grant Allocation

$$P1(u) = D1 + D2 + D3 + M1$$
$$P1 = (1 + 3d) + m1$$
$$u = d^{n+1}m^{n+1}$$
$$P1(L) = NuRB1 + NuRB2 + NuRB3 \ldots\ldots\ldots$$
$$Average\ Allocation = \frac{P1(L)=(1+NuRB1)}{dm}$$

Equation 2: Equation per Asset Class

Water	Sanitation
$\frac{\boldsymbol{u = d^{n+1}m^{n+1}}}{\boldsymbol{P_t = P_0\,(1+r)^t}}\boldsymbol{\pi/w + 1}$ **Electricity**	$\frac{u = d^{n+1}m^{n+1}}{P_t = P_0\,(1+r)^t}\pi/s + 1$ **Solid Waste**
$\frac{\boldsymbol{u = d^{n+1}m^{n+1}}}{\boldsymbol{P_t = P_0\,(1+r)^t}}\boldsymbol{\pi/e + 1}$	$\frac{u = d^{n+1}m^{n+1}}{P_t = P_0\,(1+r)^t}\pi/sw + 1$

Figure 11: Equation per Asset Class

The above figures outline the development in asset classes per province for urban and rural areas and compare the growth rate of resource distribution. These algorithms emphasise the resource allocation per province for both local and district municipalities. Additionally, asset classes such as water supply, electricity and solid waste are projected for effective resource allocation per rural and urban areas. The above stipulated resource allocation per asset class is dependent on the application of the two theories which is the baseline in development of the conceptual model. In this study resource allocation theory is aligned based on the following for the formation of the model: i) budgetary allocation, ii) public expenditure, iii) economic activity, and iv) political influences. The second theory of interpretation for the development of this model is the situational awareness theory which focuses on three main artifacts: i) perception of current situation (pcs), ii) comprehension of current situation (ccs), iii) projection of future status (pfs). The below formula addresses the initial stage in determining resource allocation based on situational awareness developed through observation and data collection based on the perception and resource allocation theory through the snowballing sampling strategy. The second stage is to comprehend the current situation as per the data collected during the perception phase and finally project the future resource allocation output for the NRBs.

$$(ra)^n = bp(1+x)^n - pe^n if \sum_{pi=0}^{ea} = \frac{-sa \pm \sqrt{pcs^o - pcs^p}}{P_0\,(1+r)^t}$$

CONCLUSION

Rural areas are lagging behind in development as the main focus of infrastructure development seems to be more effective in urban areas. Rural infrastructure is a challenge in African countries, stipulated are the fundamental conceptions of challenges faced by rural communities due to lack of infrastructure development. It further denotes the importance of exercising an effective infrastructure funding model in the NRB environment. Existing infrastructure and funding related frameworks and models are explored to determine their use as successes in their respective field of implementation. The study further demonstrates the importance for the existence of effective infrastructure funding models. On this note, the South African Local Government Association (SALGA) made efforts to encourage the implementation of an infrastructure funding model for rural development, however little progress is recorded. This therefore left the position of the NRB areas unchanged, with challenges of no service delivery or services that are non-existent.

In this light, rural municipalities are dependent on government transfers as part of revenue generation base, it is eminent that rural municipalities will continue to be dependent on provincial municipalities unless they can achieve self-sufficiency. It is acknowledged that the NRB areas are dependent on donors and government transfers for execution of service delivery. However, this mammoth challenge can be overcome through the implementation of an effective infrastructure funding model. The development of an effective Infrastructure Funding Model is not only critical, but also is a dependency for the successful implementation of rural infrastructure. The developed model intends to address the needs that arise for each asset class in different local municipalities. Now it is clear that government does not have a reliable and consistent infrastructure funding model, this therefore resulting in the slow

economic growth in rural areas. Therefore, it is imperative for this study to develop an effective infrastructure funding model for the improvement and enhancement of asset classes as per the different local municipalities located in the rural non-urban and borderline areas.

RECOMMENDATIONS

Established literature shows that for successful infrastructure development rural development cannot be donor or transfer dependent alone, hence the need for private sector involvement. It is projected that rural infrastructure development can be a reality upon correct implementation of an infrastructure funding model, as other countries have executed with efforts from government and private sector combined.

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PROTECTING CRITICAL INFRASTRUCTURE IN THE DIGITAL AGE: ANALYSING CYBERSECURITY THREATS AND COUNTERMEASURES

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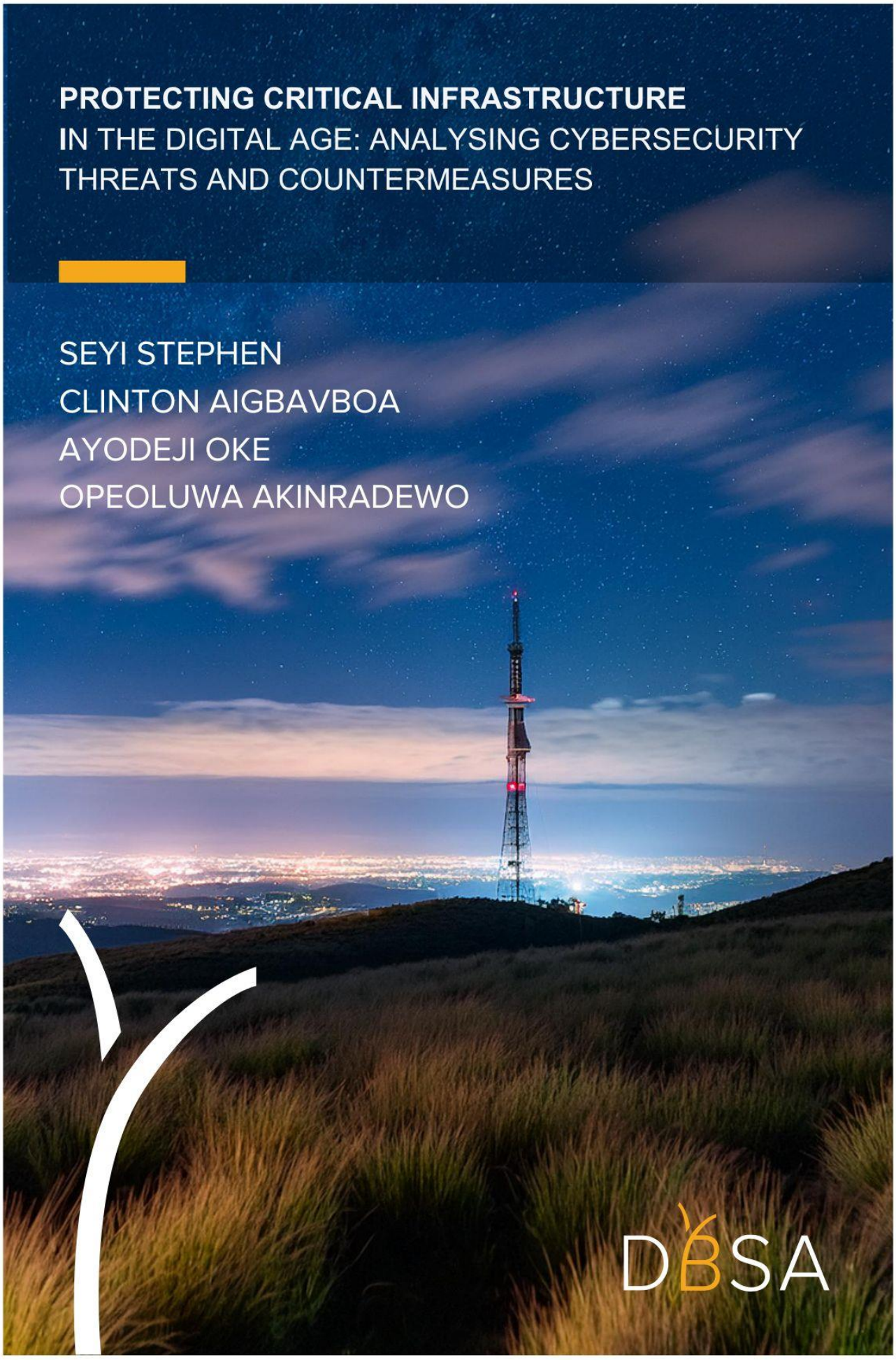

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PROTECTING CRITICAL INFRASTRUCTURE IN THE DIGITAL AGE: ANALYSING CYBERSECURITY THREATS AND COUNTERMEASURES

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ABSTRACT

This study explored the concerns surrounding infrastructure and cybersecurity in the South African construction industry (SACI), revealing significant apprehension regarding the impact of cybersecurity threats on infrastructure resilience. A quantitative research approach was employed, involving the distribution of 86 structured questionnaires to key construction stakeholders, including architects, engineers, builders, and quantity surveyors, alongside cybersecurity experts. The data collection process spanned four months and utilized random sampling techniques to ensure diverse participation. Data analysis incorporated descriptive statistics, exploratory factor analysis (EFA), and non-parametric tests such as the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity to validate the results. The findings revealed that two-factor authentication emerged as the most effective cybersecurity practice, followed by one-time passwords, firewalls, and encryption techniques. Other important practices included utilizing threat intelligence, adopting a comprehensive and strategic cybersecurity approach, and implementing incident preparedness plans. The study highlighted the dynamic, evolving, and sophisticated nature of cybersecurity threats, necessitating adaptive and responsive countermeasures. Ongoing research, continuous innovation, and proactive strategies are essential to maintaining infrastructure resilience in the face of emerging digital threats. Additionally, continuous cybersecurity training, education, and awareness programs tailored for construction stakeholders are crucial for mitigating potential risks. Furthermore, the study emphasised the importance of fostering collaboration between government agencies, infrastructure operators, construction professionals, and cybersecurity experts to develop and implement effective, adaptive cybersecurity strategies. The contribution of the study lies in its focus on protecting critical infrastructure by addressing cybersecurity challenges, thereby ensuring that the systems supporting modern society continue to function efficiently, safely, and without disruption.

Keywords: Adaptive strategies, Countermeasures, Critical infrastructure, Cybersecurity, Digital Age

INTRODUCTION

As the world is connected, safeguarding critical infrastructure has become paramount as we navigate the complexities of the digital age (Argyroudis et al., 2022). The threat landscape has evolved dramatically with the increasing integration of technology into essential systems like energy grids, transportation networks, and financial institutions (Lukasik, 2020). Humayun et al., (2020) stated that cybersecurity threats loom large, ranging from sophisticated nation-state attacks to opportunistic cybercriminal activities. Understanding these threats and implementing effective countermeasures is essential to ensure the resilience and reliability of our critical infrastructure.

According to Lehto (2022), background research reveals a concerning trend, namely that the frequency and sophistication of cyber-attacks targeting critical infrastructure are rising. Incidents such as the 2015 Ukrainian power grid attack and the 2020 SolarWinds supply chain breach underscore the vulnerability of essential systems to malicious actors (Rees and Rees, 2023). These attacks disrupt operations and pose significant security, public safety, and economic stability risks. Addressing cybersecurity vulnerabilities becomes an urgent priority as our reliance on digital systems grows.

Despite increased awareness and investment in cybersecurity, a notable knowledge gap persists regarding the most effective strategies for protecting critical infrastructure in the digital age, especially in developing countries (Schmitt, 2023). While various frameworks and technologies exist, determining the optimal approach remains challenging. Additionally, the evolving nature of cyber threats requires continuous adaptation and innovation in defensive measures. Bridging this gap requires comprehensive research that analyses emerging threats, evaluates existing countermeasures, and identifies areas for improvement. By addressing these gaps in knowledge, the study aims to evaluate strategies to mitigate cyber risks and safeguard our critical infrastructure effectively.

LITERATURE REVIEW

Cybersecurity Threats in Critical Infrastructure

Critical infrastructure refers to the essential systems, services, and assets for society, economy, and national security (Argyroudis et al., 2022). It cuts across energy, transportation, water, communications, healthcare, financial services, emergency services, etc. (Schmitt, 2023). Protecting critical infrastructure in the digital age is increasingly challenged by cybersecurity threats, necessitating robust countermeasures to mitigate risks and ensure resilience (González-Granadillo, González-Zarzosa and Diaz, 2021). Dhirani, Armstrong and Newe (2021) and Djenna, Harous and Saidouni (2021) have extensively explored the evolving landscape of cyber threats targeting critical infrastructure sectors such as energy, transportation, healthcare, and finance. Ervural and Ervural (2018) and Coburn et al. (2019) have highlighted the vulnerability of these sectors to cyber-attacks, pandemics, extreme weather, acts of terrorism, accidents, or technical failures, emphasising the potential for widespread disruption and economic loss, as shown in Figure 1. Vulnerabilities peculiar to cybersecurity are data exfiltration, contagious malware, financial theft, cloud outages, and distributed Denial of Service (DDoS) attacks, as illustrated in Figure 2 below.

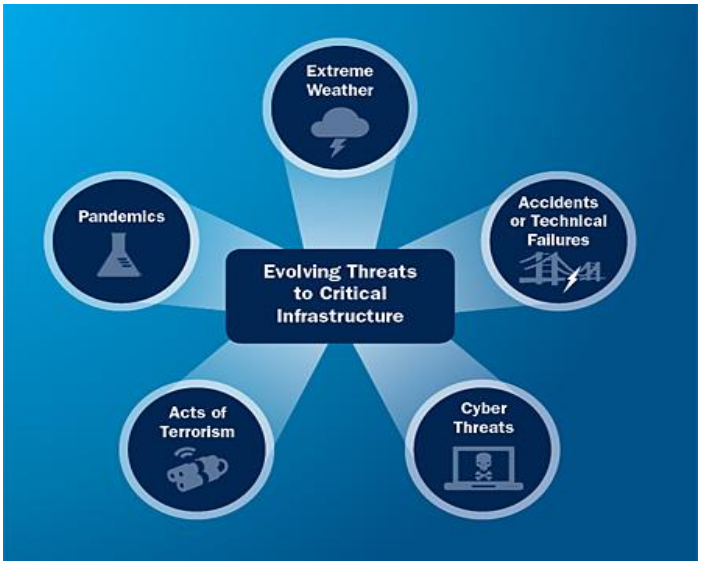

Figure 1: Evolving threats to critical infrastructure (IT-Online, 2023)

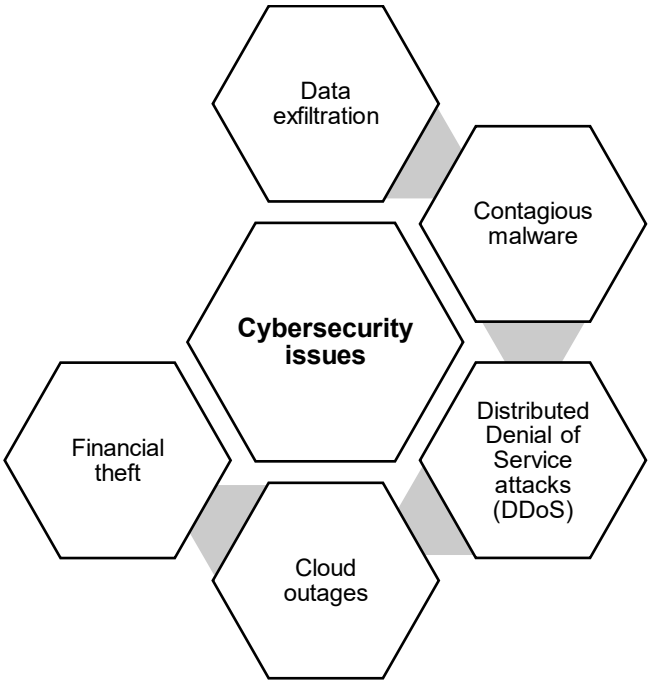

Figure 2: Issues associated with cybersecurity (Ervural and Ervural, 2018; Coburn et al., 2019)

Analysing cybersecurity threats to critical infrastructure reveals various attack vectors, including malware, ransomware, denial-of-service attacks, and insider threats. Eunice et al., (2021), Mallik et al., (2019) have investigated threat actors' tactics, techniques, and procedures to infiltrate and compromise critical systems, emphasising the need for initiative-taking defence mechanisms. As illustrated in Figure 3, the researchers summarised firewalls, intrusion detection systems (IDS), digital certificates, one-time passwords (OTP), two-factor

authentication, security tokens, digital signatures, vulnerability scanning tools, and biometrics as security tools to counter cyber-attacks.

Figure 3: Security tools for cybersecurity (Eunice et al., 2021; Mallik et al., 2019)

In response to these challenges, countermeasures and best practices have been proposed to enhance the cybersecurity posture of critical infrastructure (Shokry et al., 2022). These include implementing robust access controls, deploying intrusion detection and prevention systems, conducting regular vulnerability assessments, and fostering information sharing and collaboration among stakeholders (Di Pietro et al., 2020). Additionally, Telo (2023) stated that integrating advanced technologies such as artificial intelligence and blockchain holds promise for improving the detection and mitigation of cyber threats in critical infrastructure environments.

This section underscores the urgency of addressing cybersecurity threats to safeguard critical infrastructure in the digital age. By analysing emerging threats and deploying effective countermeasures, stakeholders can mitigate risks, enhance resilience, and ensure the continued operation of essential services vital to society and the economy, as reiterated by Vähäkainu, Lehto and Kariluoto (2022). However, ongoing research and collaboration are essential to stay ahead of evolving cyber threats and adapt to the dynamic nature of the cybersecurity landscape.

Need For Cybersecurity in Critical Infrastructure

As critical infrastructures become increasingly interconnected, a pressing need arises to defend against targeted cyber threats to disrupt or damage vital systems (Argyroudis et al., 2022). Ensuring the uninterrupted operation of essential services is imperative, as it safeguards public safety and preserves economic stability. Moreover, these infrastructures must possess interoperability capabilities with other digital technologies and practices, such

as digital twins (DT), building information modelling (BIM), artificial intelligence (AI), and smart building systems. This integration enhances overall efficiency and effectiveness, facilitating better management and response to evolving challenges in the digital age.

The transition towards real-time access to data and intelligence marks a notable change in thinking in protecting critical infrastructures, driven by the dynamic interplay between the physical and digital realms known as the Physical-to-Digital-to-Physical (PDP) loop (Kaivo-oja et al., 2020). This evolution is underpinned by eleven pillars of technological advancement encompassing big data analytics, autonomous robots, simulation and augmented reality, horizontal and vertical integration, supply chain optimisation, additive manufacturing, cloud cybersecurity, the industrial internet of things, artificial intelligence, and novel business models shown in Figure 4 (Tortorella et al., 2021). In embracing the digital era of Industry 4.0, these pillars revolutionise production processes and redefine the infrastructure necessary for future endeavours. Collaboration across government entities, individuals, organisations, and consumers facilitates realising goals within existing resources and personnel capabilities.

Figure 4: Pillars of technological advancement of Industry 4.0 (Haiston, 2023)

RESEARCH METHODOLOGY

The study employed a quantitative methodology through questionnaires to gather information about the study. This method was obtained for the study as it allows for the systematic measurement and analysis of data, providing empirical insights into the prevalence, patterns, and effectiveness of different security measures, thereby enhancing the precision and objectivity of the research findings (Zyphur and Pierides, 2017). Out of the 150 questionnaires distributed over four (4) months, 86 respondents were obtained. A random sampling was employed to select respondents from different South African construction industry professionals. It was adopted because it provides an unbiased representation of the study's population, ensuring that each member has an equal chance of being selected, which enhances the generalisability and validity of the results. The respondents were construction stakeholders (architects, builders, engineers, quantity surveyors) and cybersecurity experts in the South African construction industry (SACI). Demographic results revealed from the study regarding the background information showed that 33.8% of the SACI construction professionals had spent 6 to 10 years in the sector the responses gathered. Also, there was no bias as construction managers, civil engineers, and quantity surveyors comprise over 50% of the respondents' professions and other professions in the study's sample population.

While most respondents worked in consultancy, government and contracting firms duly represented others. Furthermore, the respondents have an average of nineteen (19) years of experience in the industry with a minimum average qualification of a bachelor's degree in relevant fields. With the respondents handling an average of ten (10) projects in construction (with relevance to modern buildings erected now), it is viable to deduce that they are more than capable of doing justice to cybersecurity-related topics in the SACI, owing to their vast academic and professional experiences in the industry. Their opinions (perceptive) are thus validated and can be relied upon now or for further studies.

RESEARCH RESULTS

Table 1 presents the mean scores, standard deviations (SD), commonalities extraction values, Kruskal-Walli's statistics, and ranks for various practices to improve cybersecurity. Two-factor authentication emerges as the top-ranked practice with the highest mean score of 4.55, followed closely by one-time passwords (4.51) and firewalls (4.48). These practices also exhibit low standard deviations, indicating an elevated level of agreement among respondents regarding their effectiveness. Other notable practices with high mean scores include utilising threat intelligence, adopting a strategic approach, and being prepared for cybersecurity incidents. On the other hand, practices like picking the right plan and personal data protection have lower mean scores, suggesting a perceived lower effectiveness. The communalities extraction values indicate the proportion of variance explained by each practice, and higher values suggest better explanatory power. The Kruskal-Wallis statistics and ranks provide insights into the variability and significance of differences among the practices. The table comprehensively overviews perceived effectiveness and variance in cybersecurity practices.

Table 1: Practices for improving cybersecurity

Practices for improving cybersecurity	Mean	SD	Communalities extraction		Kruskal-Wallis	Rank
Two-factor authentication	4.55	0.597	0.758		11.00	1
One-time password	4.51	0.737	0.573		4.40	2
Firewalls	4.48	0.598	0.609		3.00	3
Biometrics	4.47	0.661	0.680		7.61	4
Utilise threat intelligence	4.47	0.680	0.661		4.81	5
Digital signature	4.43	0.594	0.638		2.52	6
Strategic approach	4.43	0.733	0.693		3.34	7
Digital certificate	4.40	0.654	0.522		6.22	8
Be prepared for when, not if	4.40	0.799	0.819		5.50	9
Cyber liability insurance	4.40	0.712	0.710		3.71	10
Security tokens	4.39	0.610	0.621		6.36	11
Vulnerability scanning tool	4.39	0.691	0.766		10.20	12
Focus on compliance	4.39	0.652	0.799		8.45	13
Collaborate and report	4.39	0.746	0.752		5.59	14
Intrusion detection system	4.38	0.586	0.633		10.40	15
Personal data protection (PDP)	4.38	0.726	0.734		5.74	16
Private sector-initiated cybersecurity implementation frameworks	4.36	0.724	0.688		3.19	17
Evaluating risks so it is properly allocated through contract	4.36	0.724	0.611		4.76	18
Capacity building and awareness	4.36	0.647	0.593		2.66	19
Adopt a defence-in-depth approach	4.35	0.703	0.661		4.93	20
Promote a security-focused cyberculture	4.35	0.644	0.547		5.19	21
International information security standards	4.34	0.736	0.758		7.76	22
Developing national cybersecurity strategies/agendas	4.32	0.768	0.618		2.81	23
Picking the plan that is right for you	4.31	0.674	0.463		5.02	24
The role of the private sector in cybersecurity	4.31	0.693	0.725		5.49	25
Country-initiated cybersecurity implementation frameworks	4.30	0.745	0.744		6.29	26
National cybersecurity framework	4.30	0.689	0.625		6.03	27
Strengthening regional and international cooperation	4.29	0.776	0.594		9.03	28
Building a team of trusted advisors	4.23	0.759	0.519		4.80	29
Frameworks for implementing national cybersecurity initiatives	4.17	0.768	0.670		5.68	30

Source: Authors' Work

Table 2 presents the Structure Matrix and provides insights into the relationship between different cybersecurity practices and the underlying components identified through Principal Component Analysis. By examining the pattern of high loadings, or correlations, within each component, the study identifies clusters of practices that tend to be associated with each other.

Table 2: Structure Matrix

Structure Matrix					
	Component				
	1	2	3	4	5
International information security standards	0.852				
Country-initiated cybersecurity implementation frameworks	0.829				
Private sector-initiated cybersecurity implementation frameworks	0.800				
Frameworks for implementing national cybersecurity initiatives	0.783				
Cyber liability insurance	0.766				
Developing national cybersecurity strategies/agendas	0.734				
Digital certificate	0.686				
Be prepared for when, not if	0.670				
Picking the plan that is right for you	0.642				
Utilise threat intelligence	0.627				
Evaluating risks so it is properly allocated through contract	0.604				
One-time password	0.590				
Promote a security-focused cyberculture	0.541				
Two-factor authentication		0.862			
Vulnerability scanning tool		0.855			
Security tokens		0.752			
Digital signature		0.747			
Biometrics		0.701			
Focus on compliance		0.688			
The Role of the Private Sector in Cybersecurity		0.648			
Intrusion detection system			0.402		
Personal data protection (PDP)			0.825		
Strategic approach			0.819		
National cybersecurity framework			0.753		
Firewalls				0.517	
Capacity building and awareness				0.520	
Strengthening regional and international cooperation				0.441	
Building a team of trusted advisors					0.477
Collaborate and report					0.308
Adopt a defence-in-depth approach					0.672
Extraction Method: Principal Component Analysis. Rotation Method: Oblimin with Kaiser Normalization.					

Source: Authors' Work

Cluster 1: Cybersecurity Frameworks

The first component, as identified through the table above, emphasises adherence to "International information security standards (85.20%)", "Country-initiated cybersecurity implementation frameworks (82.90%)", "Private sector-initiated cybersecurity implementation frameworks (80.00%)", "Frameworks for implementing national cybersecurity initiatives (78.30%)", "Cyber liability insurance (76.60%)", "Developing national cybersecurity strategies/agendas (73.40%)", "Digital certificate (68.60%)", "Be prepared for when, not if (67.00%)", "Picking the plan that is right for you (64.20%)", "Utilize threat intelligence

(62.70%)", "Evaluating risks so it is properly allocated through contract (60.40%)", "One-time password (59.00%)", and "Promote a security-focused cyberculture (54.10%)". This cluster underscores the significance of global and national frameworks in guiding cybersecurity efforts. Compliance with established standards and frameworks is crucial for ensuring consistency and interoperability in cybersecurity practices (Maglaras et al., 2019). These standards often originate from international bodies like ISO (International Organisation for Standardisation) or regional organisations such as the European Union Agency for Cybersecurity (ENISA). On the other hand, national frameworks such as National Cybersecurity Policy Framework (NCPF) and NIST Cybersecurity Framework (CSF) 2.0 provide standardised guidelines to enhance critical infrastructure resilience against cyber threats through comprehensive risk management and regulatory compliance (NIST, 2018). By aligning with these standards and frameworks, organisations can enhance their cybersecurity posture and establish a common language for collaboration and information sharing on a global scale.

Cluster 2: Technological Security Measures

The second component highlights the importance of technological security measures such as "Two-factor authentication (86.20%)", "Vulnerability scanning tool (85.50%)", "Security tokens (75.20%)", "Digital signature (74.70%)", "Biometrics (70.10%)", "Focus on compliance (68.80%)", and "The role of the private sector in cybersecurity (64.80%)". These practices emphasise the implementation of advanced authentication protocols and tools to safeguard digital assets and sensitive information. Two-factor authentication, for instance, adds an extra layer of security by requiring users to provide two forms of identification before accessing a system (Di Pietro et al., 2020). Similarly, vulnerability scanning tools help identify and mitigate potential security weaknesses within an organisation's information technology (IT) infrastructure (Chadwick et al., 2020). Biometrics, using unique biological characteristics for authentication, offers a robust method for verifying user identities (Telo, 2023). Incorporating these technological measures is essential for mitigating cyber threats and protecting against unauthorised access to systems and data.

Cluster 3: Risk Management and Preparedness

The third component focuses on practices related to risk management, preparedness, and strategic planning for cybersecurity incidents. Concepts such as "Intrusion detection system (40.20%)," "Personal data protection (PDP) (82.50%)," "Strategic approach (81.90%)," and "National cybersecurity framework (75.30%)" underscore the initiative-taking approach needed to address evolving cyber threats (NIST, 2021). Effective risk management involves identifying, assessing, and prioritising potential risks to an organisation's assets and implementing appropriate controls to mitigate these risks (ISO/IEC, 2018). By utilising threat intelligence and evaluating risks, organisations can allocate resources efficiently and respond effectively to cybersecurity incidents (NCSC, 2020). This cluster highlights the importance of adopting a comprehensive risk management framework to enhance resilience and minimise cyber-attacks' impact on operations and reputation.

Cluster 4: Organisational and Cultural Practices

The fourth component emphasises organisational and cultural aspects of cybersecurity, including practices like “Firewalls (51.70%),” “Capacity building and awareness (52.00%),” and “Strengthening regional and international cooperation (44.10%)”. Building a strong cyber culture within an organisation involves fostering awareness, accountability, and shared responsibility for cybersecurity (Uchendu et al., 2021). Compliance with regulations and industry standards is also critical for demonstrating due diligence and minimising legal and financial risks associated with data breaches (Meglio, 2020). Additionally, recognising the role of the private sector in cybersecurity collaboration and information sharing is essential for addressing cyber threats effectively (Trim and Lee, 2021). This cluster underscores the significance of integrating cybersecurity into organisational culture and operations to establish a resilient security posture.

Cluster 5: Privacy and Regulatory Compliance

The fifth component highlights practices related to privacy protection and regulatory compliance in cybersecurity. Concepts such as “Building a team of trusted advisors (47.70%),” “Collaborate and report (30.80%),” and “Adopt a defence-in-depth approach (67.20%)” underscore the importance of safeguarding sensitive information and adhering to legal requirements (Wallis, Johnson and Khamis, 2021). As mentioned in this cluster, firewalls are essential network security components that regulate incoming and outgoing traffic based on predefined security rules (Nife and Kotulski, 2020). A strategic approach to privacy and compliance involves understanding regulatory obligations, implementing appropriate controls, and continuously monitoring and adapting to changes in the regulatory landscape (NIST, 2017). By prioritising privacy protection and regulatory compliance, organisations can build trust with stakeholders and mitigate the risk of regulatory penalties and reputational damage associated with data breaches.

Table 3 below presents the results of two key statistical tests for factor analysis and data reduction: Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity. The KMO value is high at 0.885, close to 1, indicating that the dataset is highly suitable for factor analysis. A KMO above 0.6 is acceptable, and above 0.8 is particularly good. The "Approx. chi-square" value is 1630.827, with 435 degrees of freedom and a significant p-value of 0.000 from Bartlett's test, supporting the rejection of the null hypothesis. This implies compelling evidence of correlation among variables, justifying factor analysis.

Table 3: KMO and Bartlett's test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin measure of sampling adequacy.		0.885
Bartlett's test of sphericity	Approx. Chi-Square	1630.827
	df	435
	Sig	0.000

Source: Authors’ Work

DISCUSSION

In this study, the efficacy of various cybersecurity practices is evaluated systematically. Two-factor authentication is the most effective practice, closely followed by one-time passwords and firewalls. Notable practices include utilising threat intelligence, adopting a strategic approach, and being prepared for cybersecurity incidents. Conversely, picking the right plan and personal data protection receive lower perceived effectiveness scores. The study emphasises the importance of practices aligning with international cybersecurity standards and technological security measures for a comprehensive overview of perceived effectiveness and variance in cybersecurity practices, especially in a developing nation like South Africa.

The outlined measures above play a crucial role in safeguarding critical infrastructure by implementing a series of robust security layers and protocols. These strategies are designed to mitigate cyber threats effectively, incorporating advanced authentication methods like two-factor authentication and biometrics. Additionally, initiative-taking measures such as intrusion detection systems and the utilisation of threat intelligence further enhance security measures. Collaborative efforts, alongside adherence to national cybersecurity frameworks and private sector standards, bolster resilience and ensure a unified approach to defending critical infrastructure against cyber-attacks.

It can be inferred that the study provides a comprehensive assessment of cybersecurity practices, revealing insights into their perceived effectiveness and variance. The clusters highlight the importance of cybersecurity frameworks, technological security measures, risk management, organisational culture, and privacy protection in building a robust cybersecurity posture. Organisations are encouraged to prioritise these practices to enhance their resilience against evolving cyber threats and potential breaches.

CONCLUSION

The findings of this research underscore the multifaceted nature of cybersecurity, and the diverse array of practices organisations must employ to mitigate cyber threats effectively. Evaluating mean scores, standard deviations, and other statistical measures provides valuable insights into these practices' perceived effectiveness and variability. Two-factor authentication emerges as a top-performing practice, closely followed by technological security measures and initiative-taking risk management strategies. Additionally, adherence to international standards, integration of cybersecurity into organisational culture, and emphasis on privacy protection and regulatory compliance are crucial components of a comprehensive cybersecurity framework. By understanding the strengths and weaknesses of different practices, organisations can tailor their cybersecurity strategies to address specific vulnerabilities and enhance overall resilience against cyber-attacks.

Recognising critical infrastructure's indispensable role as the foundation of modern society, it becomes imperative to delve deeper into its intricacies through further studies. Critical infrastructure sustains essential services and economic activities and drives the achievement of the Sustainable Development Goals (SDGs) and the Africa Agenda 2063. By focusing on cybersecurity, this study contributes to SDG 9, which emphasises building resilient infrastructure and fostering innovation, and SDG 16, which promotes peace, justice, and strong institutions. Strengthening cybersecurity ensures the integrity and reliability of critical

infrastructure, which is vital for sustainable economic growth and societal stability. Additionally, the research aligns with Africa Agenda 2063's goals of fostering a secure and interconnected continent, promoting technological advancements, and ensuring robust and resilient infrastructure to support Africa's transformation and inclusive growth. Through proactive cybersecurity strategies, we can safeguard essential services, protect economic assets, and enhance the overall development framework across the continent.

Amidst the rapid integration of digital technologies into these vital systems, a pressing need arises to comprehend their digital vulnerabilities. The heightened reliance on digital infrastructure consequently amplifies the susceptibility of these systems to cyber threats. Thus, prioritising cybersecurity measures is paramount in safeguarding critical infrastructure. By doing so, we ensure the resilience of these foundational systems, mitigate potential disruptions to society, and uphold national security imperatives. Moreover, the clustering of practices highlights distinct thematic areas within cybersecurity, emphasising the importance of a functional approach encompassing technological, organisational, and regulatory dimensions. From adhering to international standards to fostering a culture of security within organisations, each cluster offers valuable insights into the multifaceted nature of cybersecurity challenges. Moving forward, organisations must prioritise adopting effective cybersecurity practices identified in this research to strengthen their defences against an increasingly sophisticated threat landscape. By continuously evaluating and refining their cybersecurity strategies, organisations can adapt to evolving threats and safeguard their digital assets, mitigating cyber incidents' potential financial, reputational, and operational impacts.

RECOMMENDATIONS

Based on the findings of this research, several recommendations can be made for further exploration and action. Firstly, future research endeavours could delve deeper into understanding the underlying factors contributing to the perceived effectiveness of cybersecurity practices. This could involve qualitative studies to gain insights from stakeholders regarding their experiences and perceptions of various practices. Additionally, longitudinal studies could track the evolution of cybersecurity practices over time to assess their long-term efficacy and adaptability to emerging threats. Furthermore, interdisciplinary research collaborations between cybersecurity experts, behavioural scientists, and policymakers could facilitate a better understanding of the human factors influencing cybersecurity practices and organisational decision-making.

In addition, investing in resilience emerges as a pivotal strategy in addressing the imperative of fortifying critical infrastructure against cyber threats. Allocating resources towards developing resilient infrastructure bolsters its capacity to withstand future cyber incidents. It facilitates swift recovery, thus safeguarding the continuity of essential services and upholding national security imperatives. Moreover, continuous monitoring is another crucial measure in the defence arsenal. Organisations can detect and swiftly mitigate real-time cybersecurity risks by establishing mechanisms for ongoing surveillance and gathering threat intelligence. This initiative-taking approach enhances the defensive posture of critical infrastructure

systems, ensuring their readiness to counter emerging threats effectively, which aids disaster management.

Regarding stakeholders, organisations are encouraged to prioritise investments in cybersecurity practices that have demonstrated effectiveness and resilience. This involves adopting technological solutions and fostering a culture of security within the organisation. Stakeholders should collaborate with industry partners, government agencies, and regulatory bodies to share best practices, exchange threat intelligence, and advocate for cybersecurity resilience policies. Furthermore, ongoing education and training programs should be implemented to enhance cybersecurity awareness and skills among employees at all levels of the organisation. By engaging stakeholders and fostering a collective commitment to cybersecurity, organisations can effectively navigate the complex cybersecurity landscape and mitigate the risks posed by cyber threats.

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