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Cloud Computing Diffusion in South Africa, Kenya, and Rwanda

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Completed Research Paper

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Abstract

Domestic cloud computing is a significant driver for economic and societal development in less developed countries. The diffusion of domestic cloud computing depends on a sufficient data center infrastructure. This research investigates the factors driving the deployment of a data center infrastructure for promoting the diffusion of domestic cloud computing – and ultimately economic growth and investment – in South Africa, Kenya, and Rwanda. It explains critical gaps in local country contexts. We draw on secondary data from national policy papers and publicly available country-specific reports and statistics. Our analysis shows that provider competition provides the best conditions in South Africa. However, we find significant shortfalls especially rural Kenya and Rwanda in spite of dedicated national ICT deployment strategies that aim at promoting cloud computing. We conclude with outlining directions for future research.

Keywords: Cloud Computing, Data centers, Africa, Socio-economic development.

Introduction

A successful diffusion of domestic cloud computing has been widely accepted as a driver for economic accomplishments and societal development, particularly in less developed countries. Cloud computing specifically reduces initial capital, infrastructural, and operational expenditure for new entrants in the economy (Popirlan et al., 2020; Etro, 2009). However, the successful diffusion of cloud computing depends on a country's data center infrastructure and regulatory frameworks to support diffusion and adoption of cloud computing (UNCTAD, 2013).

Moreover, cloud computing diffusion is acknowledged as an emerging indicator that replaces or complements traditional physical computing resources. Although often seen as an abstract or virtual concept, cloud computing depends on physical infrastructure housed in data centers that are located across the globe. Domestic access to cloud computing services alone does not require a domestic cloud infrastructure.

This work investigates the data center infrastructure and the diffusion of domestic cloud computing in South Africa and the East African region. South Africa ranks higher in the Information and Communication Technology (ICT) Development Index of the International Telecommunication Union (ITU) than any East African country. Among East African countries, Kenya and Rwanda rank highest. Their fast ICT deployment has caught international attention (Ntale et al., 2013; Uwamariya & Loebbecke, 2020).

Drawing on secondary data sources, we offer an analysis of national infrastructural factors and formal institutions – i.e., the power infrastructure, the broadband infrastructure, and public policies and regulations. We aim at explaining critical digital gaps in local countries' contexts that may offer directions for where to focus economic growth efforts and ICT investments.

The remainder of this paper is organized as follows. In the next section, we present the basic concepts related to data centers and the diffusion of domestic cloud computing. We then introduce our approach to data collection and the criteria we use for our analysis. We present our comparative analysis of the data center infrastructure and the diffusion of domestic cloud computing, considering the respective national public policy and regulatory framework in South Africa and the two East African countries. We conclude with a summary of findings and suggestions for further research.

Data Centers and Cloud Computing

Data center infrastructure refers to the organization of information technology (IT) and supporting equipment inside a data center facility (Barroso, Cli-daras, & Hoelzle, 2013). Cloud computing, on the other hand, enables ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (Mell & Grance, 2011), typically housed in data centers. Cloud computing has become essential in many sectors including, but not limited to, financial services, media, high-tech, educational and governmental institutions. Cloud computing and sufficient access to data centers have therefore become essential for the development of any country.

Data centers differ with regard to the operator type, the facility type, redundancy, and – in the case of data centers run by service providers – the business model (Barroso et al., 2013; Geng, 2015).

Operator type. *Internal data centers* are operated by a single organization for supporting its activities. For instance, data centers run by service providers, so-called '*service provider data centers'*, are operated by an organization whose core business is the provision of communication and IT services (Shehabi et al., 2016). Both classes comprise similar types of data center facilities.

Facility type. Data centers differ in *size* range from less than nine square meters to up to over 37,000 square meters with different requirements for power and cooling (Benson et al., 2010; Kosik, 2015). The facility types include server closets, server rooms, localized data centers, mid-tier data centers, high-end data centers and service provider or hyper-scale data centers. Table 1 provides an overview of those types according to Shehabi et al. (2016).

Facility type (typical size)[1]	**Internal**	**Service provider**
Server closet (< 9m²)	Often outside of central IT control at a remote location with little to no dedicated cooling.	Usually located at primary local points of presence (POP) for the purpose of running supporting operating support systems (OSS) and business support systems (BSS) leveraging POP power and cooling.
Server room (9 – 93m²)	Usually under IT control with some dedicated power and cooling.	Usually located at secondary computer points of presence (POP) for the purpose of running operating support systems (OSS) and business support systems (BSS) leveraging POP power and cooling.
Localized data center (46 – 186m²)	Is provided with some power or cooling redundancy for constant temperature and humidity settings.	- Is provided with some power and cooling redundancy for constant temperature and humidity settings. - Set up by value added resellers to provide managed services.
Mid-tier data center (186 – 1,858m²)	Has a superior, probably redundant cooling system.	- Has a superior, probably redundant cooling system. - Used by small and mid-sized colocation/hosting provider including regional facilities for multinational communication service providers.
High-end data center (> 1,858m²)	Has advanced cooling systems and redundant power.	- Has advanced cooling systems and redundant power. - Primary server location for service providers. - May have a modular design.
Hyper-scale data center (≥ 37,161m²)	Not typical for internal data centers	- Employs advanced cooling systems and redundant power. - Primary server location for large collocation and cloud service providers. - Based on a modular design.

Table 1: Common data center facility types (Shehabi et al., 2016, p. 21)

Degree of redundancy. Data centers differ with regard to *mission-critical computation resources* promising uninterrupted operations in the case of power failures, security instances, or interrupted network connections (Geng, 2015; Park & Hanna, 2015; Uptime Institute, 2018).

Business models. Service provider data centers mostly run hosting and wholesale business models. In data centers pursuing a *hosting* business model, the ICT equipment belongs to the service provider who leases servers or space on the servers including storage capacity to rather small companies. The leasing package typically includes on-site support functions such as restarting servers and software upgrades. In *wholesale* data centers, the service provider only leases space, power, and facility operations including some telecommunication offerings to clients who bring their own IT equipment. Wholesale facilities are often set up in a modular design to optimize for security and power supply and provide future upscaling.

Cloud computing suggests five essential characteristics. Those are (1) on-demand self-service, (2) broad network access, (3) resource pooling, (4) rapid elasticity, and (5) measured service. Cloud computing can be further distinguished along two dimensions, i.e., service models and deployment models. Cloud

[1] Values are converted from square foot to square meter.

computing resources include networks, servers, storage, applications, and services, which are all available at short-term access with minimal administrative effort. Offered in public, private, community, and hybrid clouds, cloud computing applications run on an infrastructure spread across a network of physical servers, housed in multiple data centers. Cloud computing is mostly organized as a software-as-a-service (SaaS), platform-as-a-service (PaaS), and infrastructure-as-a-service (IaaS), while some also refer to anything-as-a-service with the abbreviation XaaS. Primarily large cloud service providers use geographically distributed data centers for their services to have better end-to-end performance (Greenberg et al., 2009; Mahimkar et al., 2011). Users access services via the Internet without ever managing or controlling the cloud infrastructure.

Developmental benefits of Cloud Computing

Cloud service providers (CSPs), which are large enterprises, use geographically distributed data centers for their services in order to have a better end-to-end performance which means lower latency and high availability despite the possibility of technology or infrastructure failure (Greenberg et al., 2009; Mahimkar et al., 2011). Low latency is also important for smaller CSPs, who may build their cloud infrastructure on a network of service provider data centers. Service providers provide the possibility for companies to outsource their data center resources in order to save money and concentrate on their core business (Crosby & Curtis, 2015). Users can access the network of data centers and the cloud, via their local carrier network through POPs. In this way, they get access to the cloud computing services. However, since cloud computing services are offered over the Internet, domestic access to cloud computing services does not require a domestic cloud infrastructure (UNCTAD, 2013). Instead, cloud computing services can be hosted on data center infrastructure on foreign ground and then be accessed via international Internet connections.

In recent years, there has been a trend of moving the processing and storage of data from traditional data centers to so-called 'cloud data centers'. Those are large-scale data centers with enormous computing capacities that allow for economies of scale and scope (Barroso et al., 2013). They often offer comparatively low prices to the end-user – typically charged as a pay-as-you-go model. Different from renting/leasing, hosting, and wholesale arrangements, such pay-as-you-go models exclude the cost of overprovisioning computing resources (Armbrust et al., 2009).

The main economic growth and developmental benefits for organizations choosing to rely on cloud computing services are the low cost of initial capital expenditure (CapEx) and operational expenditures (OpEx) (Popirlan et al., 2020; Rafique, et al., 2011), combined with the flexibility and speed of up or down scaling of computing resources according to current needs. This is especially the case for greenfield operations with limited budgets, as upfront deployment and investment risks become minimal (Dhar, 2012).

Research Approach: Data Collection, Themes and Criteria

As indicated, the aim of this work is to analyze and compare South Africa and the East African countries with regard to domestic data center infrastructure and cloud computing diffusion. For the comparison, we collected secondary data for Kenya and Rwanda as representative of the East African region and of South Africa. We draw the data from country-specific reports and statistics available from the United Nations, World Bank, the International Telecommunications Union, national policy papers, and other publicly available sources.

With regard to benefiting from cloud computing, new economic ventures in developing countries often face challenges related to immature policy and regulation, accessing cloud computing services, infrastructural issues, and start-up expenditure. Hence, we identified three main themes for organizing our analysis. These are (1) the power infrastructure, (2) the broadband infrastructure, and (3) applicable national public policy and regulatory frameworks. Analyzing our secondary sources, we identify (1) the availability, (2) the quality, and (3) the cost of each of the three themes as the most relevant criteria and as helpful guide for our subsequent analysis.

Table 2 provides an overview of the main themes and criteria identified in secondary data sources.

	South Africa	**Kenya & Rwanda**
	Power Infrastructure	
Availability	Eskom (2019); Lawrence Berkeley National Laboratory (2018a); Newbery & Eberhard (2008); World Bank (2019)	Lawrence Berkeley National Laboratory (2018b); Lawrence Berkeley National Laboratory (2018c); Rwanda Energy Group (2018); World Bank (2019)
Quality	Eskom (2017, 2018a)	D'Hoop et al. (2016); Republic of Rwanda (2015a)
Cost	Eskom (2018b)	Energy Regulatory Commission [Kenya] (2013); Republic of Rwanda (2015a); Rwanda Utilities Regulatory Authority (2016)
	Broadband Infrastructure	
Availability	International Telecommunication Union (2017a); South Africa Department of Communication (2013); TeleGeography (2017)	International Telecommunication Union (2017a, 2018); Kenya ICTA (2013a); Msimang (2011); Republic of Kenya (2016); Republic of Rwanda (2015b); TeleGeography (2017); World Bank (2015)
Quality	International Telecommunication Union (2017a, 2017b); South Africa Department of Communication (2013)	BBC News (2012); International Telecommunication Union (2017a); Kenya ICTA (2013a); World Economic Forum INSEAD (2013)
Cost	Internet Service Providers' Association (2018); Prieger (2013); South Africa Department of Communication (2013)	International Telecommunication Union (2017a); International Telecommunication Union (2016, 2017a); Kenya ICTA (2013a); Republic of Rwanda (2013); World Bank (2015)
	Public Policy & Regulatory Framework	
	Independent Communications Authority of South Africa (2010); South Africa Department of Communication (2013); South Africa Telecommunications and Postal Service Department (2016)	Communications Authority of Kenya (2010); Kenya ICTA (2013b, 2014); Kenya ICT Board (2013); Republic of Kenya (2016); Republic of Rwanda (2015b, 2015c, 2016)

Table 2. Themes and criteria identified for further analysis

To further illustrate the developmental potential and possible challenges of cloud computing diffusion, Table 3 compares selected ICT and socio-economic indicators for the three countries.

Indicator	**South Africa**	**Kenya**	**Rwanda**
Human Development Index (HDI) in 2020	High HDI	Medium HDI	Low HDI
Total population in 2017	53.8 m	47.9 m	12.7 m
Rural population with access to electricity in 2017	89.6%	71.7%	23.4%
Gross National Income (GNI) per capita in 2017	$5480	$1380	$700
ICT Development Index (IDI) value in 2017	4.96	2.91	2.18
ICT Development Index (IDI) rank in 2017	92	138	153
Percentage of households with Internet access in 2017	52.96%	22.3%	9.3%
Fixed (wired) broadband subscriptions per 100 inhabitants in 2017	2.84	0.33	0.17
Active mobile-broadband subscriptions per 100 inhabitants in 2017	58.62	26.16	27.1

Table 3. Comparative ICT and socio-economic indicators (International Telecommunication Union, 2017b; United Nations Development Programme, 2020)

Power Infrastructure

The power infrastructure is crucial for operating a data center facility (Baudry, 2015). It is important for running IT equipment, servers, and storage systems and for support like cooling and lighting (Pelley et al., 2009). The bulk of research on making data centers and cloud computing more energy-efficient reflects the importance of the topic (Depoorter et al., 2015; Hartmann & Farkas, 2016; Mazumdar et al., 2017; Pakbaznia & Pedram, 2009; Shehabi et al., 2011). The power requirements for a diffusion of domestic cloud computing are the same as for operating domestic data center infrastructure. As stated above, we analyze the national power infrastructure according to the three criteria (1) availability, (2) quality, and (3) cost.

The *availability* of the power infrastructure refers to the availability of connections to the power grid or other power sources and the amount of power load[2] provided by those sources (Depoorter et al., 2015). The peak power load determines the amount of electricity that a power source must provide for a data center. The required power load sets restrictions on the potential geographical location of a data center.

The *quality* of the power infrastructure relates to lengths of uninterrupted power supply to meet uptime requirements. It depends on the redundancy of the electrical systems (Geng, 2015; Park & Hanna, 2015). Uninterruptible Power Supply Systems (UPS) differ in the type of additional power source (battery or diesel generator) and in the response time (speed of switching from primary to additional power source). Higher redundancy comes with higher initial investments and operating costs (Loeffler & Spears, 2015).

The *costs* of the power infrastructure determine the business case of a data center. The industrial tariffs for power – capacity charge[3] and the utility price[4] – amount to a substantial share of the occupancy cost for a data center (Barroso et al., 2013; Baudry, 2015; Greenberg et al., 2009). Data centers are often located in remote areas near power stations (Lam et al., 2010), hence away from users. This geographical setting demands long-distance data transmission. Such data transmission is typically cheaper than long-distance high-voltage power transmission (Armbrust et al., 2009). Nevertheless, in developing countries, remote

[2] Power load reflects the amount of electricity a facility draws from the power grid or another power source in order to operate, measured in megawatt (MW).

[3] Price for the subscribed power load.

[4] Cost per kWh.

locations often lack the infrastructure for either one or both transmission types (Kshetri et al., 2017). This limits geographic strategies for saving power costs.

Broadband Infrastructure

The broadband infrastructures for exchanging data with the outside world greatly influence data center and cloud computing services delivery to users (UNCTAD, 2013). Again, we distinguish (1) availability, (2) quality, and (3) cost of a country's broadband infrastructure.

The *availability* relates to the national and the connection to international broadband infrastructure. Connections among data centers and between data centers and users are crucial for a large-scale domestic diffusion of cloud computing. Local exchange carriers, who run traffic to exchange and pass it on to long-haul carriers, typically provide data centers with an access circuit in and out of the facility. Long-haul transmission lines bridge the distance between data centers or between a data center and the users' location (Lam et al., 2010).

The network of domestic long-haul transmission lines builds the national backbone of broadband connections. It restricts the potential locations for data center facilities required for a diffusion of domestic cloud computing. Landing points of submarine cables are popular sites for data centers (Geng, 2015), requiring local access networks including local loops and the fixed or mobile last mile (Nandi et al., 2016). As stated above, national use of cloud computing services is also possible through accessing cloud computing services hosted in data centers abroad. In those cases, the connection to international broadband infrastructure via terrestrial and submarine cables is essential (UNCTAD, 2013).

The *quality* of the broadband infrastructure refers to the available bandwidth capacity on the different network levels. The theoretically available throughput rates influence the possible quality-of-service of data delivery. Download speed and upload speed are constrained by the characteristics of the last mile (Gonsalves & Bharadwaj, 2009). 'Slow networks' preclude the use of cloud computing use for time-sensitive services such as web conferencing or stock trading.

The *cost* of using the broadband infrastructure include wide-area-networking costs (peering, inter-data center links) and the cost for connecting regional facilities (Greenberg et al., 2009). The data transmission cost depends on the required data transmission rates and the tariffs offered by the regional long-haul carriers (Baudry, 2015).

National public policy and regulatory framework

Cloud computing and related trends place pressure on governments to develop a public policy and install a regulatory framework that ensure policy compliance and cross-border regulatory cooperation. Governments are concerned about becoming dependent and vulnerable when transferring critical commercial data to foreign data centers (Pearson & Benameur, 2010; Theoharidou et al., 2013). They fear that trans-border data flows become a means to circumvent national laws (De Hert & Boulet, 2013; Kuner, 2010). They aim at establishing – at least to some degree harmonized – policies related to trans-border data flows, data protection and privacy, data processing risks and security, which exclude circumventing national laws and moving economic activities abroad (Duncan & Whittington, 2016; Hon et al., 2012; Kuner, 2010; Seddon & Currie, 2013).

In the context of promoting data centers, trans-border data transfers and the diffusion of domestic cloud computing, a national broadband plan is typically a political indicator for wishing to support domestic cloud computing as a means to achieve economic growth. For example, China appears to hamper its uptake of domestic cloud computing services with its cyber-control measures (Kshetri et al., 2017), which makes it difficult or even impossible for users to access cloud computing services offered by foreign providers. In Sub-Saharan Africa, the lack of a local power and broadband infrastructures – and the widespread unaffordability to access what is available – hamper the uptake of data-related services - even though national policies states differently (Kshetri et al., 2017). Furthermore, there may be a gap between establishing a regulatory framework and the ability to enforce the regulations.

Findings and Discussion

Power Infrastructure

In terms of the availability, quality, and cost of the power infrastructure, South Africa provides the most extensive data center landscape and thereby the best conditions for the diffusion of domestic cloud computing. Power infrastructure shortfalls force Kenya and Rwanda to focus more on accessing international cloud computing services.

Availability. Due to the lack of connectivity to the electricity grid in the three countries, operating a data center in rural areas is difficult (World Bank, 2019). A data center close to a major population hub is in this respect more favorable, although even in cities there is no guarantee for good connections. In South Africa, the coverage of grid electricity throughout the country is much better than in the Kenya or Rwanda (Lawrence Berkeley National Laboratory, 2018a, 2018b, 2018c; World Bank, 2019). This results in more potential locations for data centers in South Africa than in the East African countries.

Quality. Insufficient power supply leads to scheduled electricity interruptions and uncontrolled outages (Eskom, 2017, 2018a; D'Hoop et al., 2016; Republic of Rwanda, 2015a). Data centers need to be equipped with sufficient UPSs or generators for bridging downtimes. Reliable permanent off-grid power sources for data centers help mediate the concern. Building on such off-grid power sources requires early information on power interruptions. Information on planned cut-offs is more extensive in South Africa than in the East African countries (Eskom, 2018a).

Costs. In South Africa, the location of a data center significantly influences its power availability and thereby its cost (and tariff) structure. Data centers charge more complex and differentiated tariffs depending on the geographic location and the required transmission voltage (Eskom, 2018b). In contrast, tariffs in the East African countries are relatively homogenous (Energy Regulatory Commission [Kenya], 2013; Rwanda Utilities Regulatory Authority, 2016) as there is typically only a connection to one data center that offers cloud computing services. On average, the utility prices in South Africa are lower than in Kenya and Rwanda. High utility prices make Kenya and Rwanda less lucrative for data center operations (Lawrence Berkeley National Laboratory, 2018b; Republic of Rwanda, 2015a).

In terms of the availability, quality, and cost of the power infrastructure, South Africa therefore provides better conditions than Kenya and Rwanda for data centers and the diffusion of domestic cloud computing. Hence, Kenya and Rwanda may be more interested in accessing international cloud computing services to overcome more frequent power infrastructure shortfalls.

Table 4 summarizes the key findings concerning the power infrastructure in South Africa and Kenya and Rwanda in East Africa.

Region	South Africa	East African countries
Availability	High diffusion of the electricity transmission network with good connection to major population centers presenting good conditions for Data Center operations.	Diffusion of electricity transmission network limited to specific areas partly not reaching major population centers limiting the choice of potential Data Center locations.
Quality	- Geographically diverse quality, which promotes the agglomeration of Data Center facilities at favorable locations. - In general, insufficient quality for advanced Data Center infrastructure due to scheduled power interruptions and the risk of unplanned outages. - Information platform on planned electricity cut-off is provided.	- Poor quality in large parts of the region, which promotes a very high agglomeration of Data Center facilities at favorable places. - In general, insufficient quality for advanced Data Center infrastructure due to scheduled power interruptions and the risk of unplanned outages. - No information platform on planned electricity cut-off is provided

Cost	- Geographically differentiated prices with lower price levels in urban areas and the south-west presenting a factor influencing Data Center location choice. - Lower utility prices than in the East African countries making South Africa more attractive for Data Center and cloud infrastructure operations.	- No geographic price differentiation presenting providing the concentration on other factors for the choice of Data Center locations. - Relatively high, subsidized utility prices especially in Rwanda making operations of Data Center facilities and a domestic cloud infrastructure very costly.

Table 4. Power infrastructure for data center infrastructure and cloud computing in South Africa and East African countries (Kenya and Rwanda)

Broadband Infrastructure

Availability. South Africa, Kenya and Rwanda show good international broadband connectivity. As a landlocked country, Rwanda managed to connect internationally via the landing stations of nearby coastal states (Republic of Rwanda, 2015b). With regard to connectivity on a national level, they all provide good prerequisites for long-haul data center-to-data center communications. South Africa provides the highest connection figures per capita; however, it also faces some connection problems on local access network level. In Kenya and Rwanda, only a limited number of population knots with metro access networks (International Telecommunication Union, 2017a, 2018; Kenya ICTA, 2013a; South Africa Department of Communication, 2013) make it difficult to maintain data center services and promote the diffusion of domestic cloud computing to commercial or private users.

Quality. Comparing the broadband infrastructure quality across the three countries, South Africa provides the best conditions for diffusing of domestic cloud computing (South Africa Department of Communication, 2013; International Telecommunication Union, 2017a & 2017b). The South African broadband infrastructure allows diffusing domestic cloud computing with high quality-of-service levels throughout the country. While Rwanda comes close to South African standards (Kenya ICTA, 2013a; World Economic Forum, INSEAD, 2013), Kenya lags behind concerning the quality of local access networks (International Telecommunication Union, 2017a).

Costs. Overall, broadband services are cheaper in South Africa than in Kenya and Rwanda. Across all network levels, price levels are lower and incomes higher in South Africa than in East African countries. In South Africa using the network backbone is more expensive than in the other two countries (International Telecommunication Union, 2017a; Kenya ICTA, 2013a; Republic of Rwanda, 2013), because one incumbent controls large parts of the infrastructure (South Africa Department of Communication, 2013), while prices for the local access network, the 'last mile', compete with the ones in Kenya and Rwanda. In the East African countries, competition among providers on various network levels, keeps end-user prices affordable (International Telecommunication Union, 2016, 2017a; Kenya ICTA, 2013a; Republic of Rwanda, 2013).

The overall cost situation suggests further thoughts. The overall more affordable infrastructure access in South Africa is not surprising given the fact that South Africa ranks higher on the ICT index than the East African countries and has a further developed economy (International Telecommunication Union, 2017b; United Nations Development Programme, 2020). Nonetheless, the example of broadband cost shows that the East African countries partly pursue better strategies than South Africa for the promotion of data centers and promoting the diffusion of domestic cloud computing. So far, according to our preliminary analysis, they fail to benefit from those strategies – likely due to their lower level of economic development. For all three countries, the gap between urban and rural areas in terms of data centers and the diffusion of domestic cloud computing is evident – but more pronounced in the less developed East African countries.

Table 5 recaps our main insights with regard to the broadband infrastructure in South Africa and the East African countries Kenya and Rwanda.

Region	**South Africa**	**East African countries**
Availability	- Well-diffused backbone, long-haul and metro infrastructure able to support Data Center-to-Data Center communication and a domestic cloud infrastructure. - Well-diffused metro access network in the majority of population hubs, mostly able to support Data Center-to-Data Center communication and a domestic cloud infrastructure. - Limited access network complicates especially the use of Data Center services in rural areas and private use of cloud computing services.	- Well-diffused backbone infrastructure able to support Data Center-to-Data Center communication and a domestic cloud infrastructure. - Availability shortfalls already arise at the metro network level complicating Data Center-to-Data Center and Data Center-to-user communication. - Delivery of cloud computing services possible at population hubs but very limited in rural areas.
Quality	- Data Center-to-Data Center communication and cloud infrastructure is limited in metro and backhaul networks due to incomplete fiber-roll-out - Gap of quality in local access networks limiting the classes of Data Center and cloud computing services that can be delivered with sufficient 'Quality of Service'.	- Considerably less international bandwidth per Internet user than in South Africa in connection with less suitable conditions for domestic cloud infrastructure presents inferior conditions for the use of cloud computing services with high 'Quality of Service' requirements. - Local access network with diverse quality across the East African countries providing better 'Quality of Service' conditions in Rwanda due to higher 4G coverage.
Cost	- High price level throughout the network imposes high cost on the supply of Data Center and cloud computing services. - High prices on the local access network in proportion to income level especially for fixed broadband presents a barrier to receiving Data Center and cloud computing services.	- Competitive price structure on the national and metro wholesale network creating favorable conditions for Data Center-to-Data Center communication and a domestic cloud infrastructure. - Local access network prices account for an even higher share of the individual income than in South Africa.

Table 5. Broadband infrastructure for data center infrastructure and cloud computing in South Africa and East African countries (Kenya and Rwanda)

Public Policy and Regulatory Framework

All three countries have a favorable broadband policy environment for data centers and the diffusion of domestic cloud computing. However, authorities in the less developed East African countries seem to push more strongly to deploy the technologies – perhaps because South Africa is already further developed in that respect.

In South Africa, the data center strategy focusses on educating and raising awareness about hosting data centers, promoting geographical diversification among data centers, and facilitating entrance into the hosting market (South Africa Department of Communication, 2013). Furthermore, South Africa has unique regulations for a competitive data center hosting market (Independent Communications Authority of South Africa, 2010). In contrast, South Africa does not regulate prices for hosting services. Users can choose a data center regardless of the ISP's or the data center's geographic location. Neither are there any regulations, rules or required standards concerning cloud computing.

Kenya and Rwanda pursue specific strategies and short-term plans on a granular level. Kenya promotes the deployment of a national neutral and localized data centers for securing domestic, quality-of-service cloud computing (Republic of Kenya, 2016). The country focusses on governmental data centers as basis for enhancing the delivery of government services (Kenya ICTA, 2014).

Rwanda's policy pursues the ubiquitous diffusion of domestic cloud computing as a means to foster social inclusion and economic growth. As a crucial user of domestic cloud computing, the Rwandan government is a role model to commercial and private users in the country (Republic of Rwanda, 2015c). From the perspective of the Rwandan authorities, the potential of domestic cloud computing outweighs the inherent security issues. Along these lines, Rwanda also regulates electronic communication in order to enable and facilitate electronic transactions by removing legal and operational barriers (Republic of Rwanda, 2016).

In summary, regulatory frameworks differ across the three countries – depending on the maturity of the infrastructure in the country and the economic development. Finally, Tables 6 summarize our key findings with regard to the public policies and national regulations of South Africa and Kenya and Rwanda as representative for the East African countries.

South Africa	**East African countries**
- The existence of a broadband policy indicates positive attitude towards Data Center and cloud computing services. - Data Center and cloud computing strategies are included in the ICT policy; there is no dedicated policy. - Data Center strategy is targeted at educating and raising awareness about hosting, promote geographical Data Center diversification and facilitate entrance in hosting market. - Loose regulative framework for Data Center hosting aiming to promote competition. - Cloud computing is acknowledged as knew technology with potential for helping to implement the ICT strategy. - No regulative framework for cloud computing but observing sector to identify future need for it. - Transparent regulations on the leasing of electronic facilities benefits the Data Center hosting market.	- The existence of a broadband policy indicates positive attitude towards Data Center and cloud computing services. - Data Center and cloud computing strategies are included in the ICT policy; there is no dedicated policy. - Kenya promotes the deployment of a national neutral and localized Data Center infrastructure for securing 'Quality of Service' and developing a domestic cloud infrastructure Data Center. - Strong focus on government Data Center enhancing the delivery of government services in Kenya, the government as role model. - Strong focus on cloud computing diffusion in Rwanda in order to consolidate and downsize physical ICT resources, especially Data Center infrastructure. - No specific regulations on Data Center or cloud computing but plans for development. - Enhancing regulations for electronic communications facilitating Data Center operations.

Table 6. Public policies and regulations for data center infrastructure and cloud computing in South Africa and East African countries (Kenya and Rwanda)

Conclusion, Recommendations and Further Research

In this research, we offer a comparative analysis of the national data center infrastructures and the diffusion of domestic cloud computing in South Africa and the two East African countries, Kenya and Rwanda. A key tenet of this study is that the diffusion of cloud computing will have profound economic impacts on business creation, macroeconomic performance, job creation in a variety of industries, job reallocation in the ICT sector, and the appropriation of public funds (Etro, 2009; Popirlan et al., 2020). Our three country-level analysis helps explain critical digital gaps within regions and countries along the three themes 'power infrastructure', the 'broadband infrastructure', and 'public policy and regulatory framework' in each of the three countries. These findings may also serve as recommendations for key stakeholders from countries analyzed, for where to focus cloud computing diffusion efforts and related infrastructural investment.

We find that for all three countries, infrastructure deficiencies hamper the diffusion of domestic cloud computing. While all three countries show a gap between urban and rural areas, it is especially the rural infrastructures in Kenya and Rwanda that show significant shortfalls (see Table 3). We also find differences among the analyzed countries – for instance, regarding the availability, quality, and costs of the power infrastructure. It goes without saying, that ongoing improvement of the availability, quality and cost of electricity provisioning, especially in rural areas, is needed.

According to our analysis, provider competition makes a strong difference – and points to a rather easy policy path in stimulating growth opportunities. As regards their regulatory frameworks, South Africa concentrates on educating and raising awareness about data center services and cloud computing offerings, whereas both, Kenya and Rwanda, focus more on deploying technologies. We find that all three countries demonstrate political will to develop a set of data centers which ought to strengthen the diffusion of domestic cloud computing. They all foresee that fostering domestic cloud computing would be important for stimulating social inclusion and economic growth opportunities.

Our study stresses the importance of developing and regulating ICT, specifically data centers and domestic cloud computing, for creating economic growth and inclusion opportunities. However, countries' policy and regulatory frameworks should be careful in over-regulating trans-border data flows as a way of stimulating localized economic activities. They should rather craft policies and regulation that can provide guidance with regard to cross-border cooperation, data processing risks, and security.

Our analysis and contribution also suggest that further research could follow similar thematic guidance as this study:

- In order to strengthen our explanation of themes and subsequently juxtapose our findings to other settings, future research may want to expand the systematic study of secondary data sources such as country-specific reports, national statistics, and policy documents to the North and West African regions.
- Focused qualitative case studies from different role-players in different African regions will allow for more in-depth articulation of the themes and contributions of this paper. Of particular interest would be to gather insights from greenfield ICT operations where the benefits of cloud computing may be most vivid. This should complement our insights with country-specific cases that investigate how policy and regulation align or misalign with local reality and needs.
- Further research should focus on issues and guidance related to how regulatory and policy frameworks support and/or impede economic opportunities of small businesses and ICT start-ups. Of specific interest would be issues related to the benefits of low capital and operational expenditure (CapEx & OpEx), barriers to accessing cloud services, and security related risks and regulations (Popirlan et al., 2020).
- Due to the inherent complexity and the impact of regulatory frameworks, future research should consider a detailed comparison of different regions, drawing on interdisciplinary research teams including legal experts, policy advisers, and ethnography researchers from each of the three countries, plus additional African countries.

- Contributions should consider both descriptive and prescriptive contributions (Gregor, 2006). Using similar themes as highlighted in this paper, descriptive contributions could focus on understanding the status quo of cloud computing diffusion in different African country contexts. This can then be followed with prescriptive guidance for policy and regulation, broadband and infrastructure deployment, and ICT investment, with the key underlying principle of stimulating economic growth opportunities.
- Finally, analyzing a broader data set across more African countries would allow the African community to explain, strengthen, or possibly refute our findings. Hence, practitioners and policy makers may want to encourage IS research to derive an integrative framework of cloud computing that could provide guidance to subsequent interdisciplinary efforts that foster the overall economic development of the continent. A complimentary extended analysis of the socio-economic factors driving the diffusion of cloud computing and an investigation of the economic potential of a more widespread deployment of data center infrastructure and cloud computing services ought to further benefit the community.

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