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An Economic Feasibility Model for Sustainable 5G Networks in Rural Dwellings of South Africa

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Abstract: Numerous factors have shown Internet-based technology to be a key enabler in achieving the sustainable development goals (SDG), as well as narrowing the divide between the global north and south. For instance, smart farming, remote/online learning, and smart grids can be used to, respectively, address SDGs 1 and 2 (ending poverty and hunger), 3 (quality education), and 7 and 9 (energy and infrastructure development). Though such Internet-based solutions are commonplace in the global north, they are missing or sparsely available in global south countries. This is due to several factors including underdevelopment, which dissuades service providers from investing heavily in infrastructure for providing capable Internet solutions such as 5G networks in these regions. This paper presents a study conducted to evaluate the feasibility of deploying 5G networks in the rural dwellings of South Africa at affordable rates, which would then serve as a pre-cursor for deploying solutions to improve lives and achieve the SDGs. The study evaluates the economic viability of a hybrid network model which combines terrestrial and aerial networks to provide 5G coverage in rural areas. The feasibility study reveals that such a network can be engineered at low monthly subscription fees to the end users and yield good returns to the service providers in rural areas; however, for large but sparsely populated suburban locations, the traditional terrestrial network with base stations is more suitable.

Keywords: 5G; economic feasibility; internal rate of return (IRR); sustainable development; unmanned aerial drones (UAV)

Citation: Maluleke, H.; Bagula, A.; Ajayi, O.; Chiaraviglio, L. An Economic Feasibility Model for Sustainable 5G Networks in Rural Dwellings of South Africa. *Sustainability* **2022**, *14*, 12153. https://doi.org/10.3390/su141912153

Academic Editors: Rashid Mehmood, Tan Yigitcanlar and Juan M. Corchado

Received: 30 July 2022
Accepted: 14 September 2022
Published: 26 September 2022

1. Introduction

According to the United Nation's World Economic Situation and Prospect (WESP), globally, countries fall into one of three categories based on their economy: developed economy, economy in transition, and developing economies [1]. Most of the countries in Europe, North America, and Australia are classified as developed or in transition, while those in Africa, Asia, and South America are considered developing or "global south" nations. While the global north nations lead in terms of technological advancements and high standards of living, global south nations are in contrast characterized by a human development index lower than 0.8, gross national income per capita of USD 4100 or less, dilapidated infrastructures, and limited access to basic human needs. Narrowing the gap between the global north and south countries is one of the purposes of the sustainable development goals (SDG), specifically goals one to nine: ending poverty (1) and hunger (2), access to good health (3), quality education (4), equity (5), potable water (6), energy (7), economic growth (8), and infrastructure development (9) [2].

Recent evidence has shown that technology plays a pivotal role in achieving many of the SDGs, and its adequate deployment can help in narrowing the gap between the global north and south nations. For instance, by applying smart agricultural practices, crop yield can be improved to address world hunger [3], while wireless body sensors and the Internet of Things (IoT) can be used to monitor patients remotely [4,5]. Similarly, cloud collaboration can be used to improve infrastructure and economic growth [6], online and remote learning to provide quality education [7], and sensor networks to monitor water quality for drinking and irrigation [8]. A common factor among these technological solutions is a good communication network, which enables the interconnection of millions of access networks scattered across the world, as well as providing billions of global users with access to these networks via the Internet. Hence, both the Internet and next-generation mobile networks can be considered primary enablers of sustainable development.

The rapid proliferation of mobile devices and the corresponding growth in the volume of multimedia data traffic have necessitated the push to re-architect the current generation of cellular mobile communication and move into the fifth generation of cellular technology. The fifth generation (5G) is characterized by three unique features, viz., ubiquitous connectivity, extremely low latency, and ultra-high-speed data transfer [9]. The fifth generation has been introduced with the promise of unlimited bandwidth, lower latencies, and virtualization capabilities, enabling network operators to meet the expected capacity demand from a multitude of emerging bandwidth-hungry and real-time applications. On the other hand, in an emerging ICT sector aiming at tremendous increases in bandwidth, reduction in latency, and drastic emissions reduction to mitigate the impact of climate change, 5G will enable many industry sectors to align with different SDGs, including:

- SDG 3, related to "good health and well-being", by using smart wearables to increase the efficiency and effectiveness of medical treatments.
- SDG 4, related to "equitable quality education", by enabling quality education via online channels without the need for large-scale land and construction.
- SDG 8, related to "decent work and economic growth", by providing faster data access leading to improved human performance, increased skills, and inclusive growth.
- SDG 9, related to "industry, innovation and infrastructure", by relying on its underlying technologies to increase precision in manufacturing, can save materials and energy.
- SDG 11, related to "sustainable cities and communities", by using the integration of 5G and IoT to optimize transport, traffic, and city transformation by citizens.
- SDG 13, related to "climate action", by building around 5G to digitize a range of services and industries and therefore reducing greenhouse gas emissions and global warming, while simultaneously saving energy.

Though Internet penetration has improved significantly in the past few decades, many global south countries still lag their northern counterparts. Several factors are responsible for this lag, including inadequate electricity supply (goal 7), poor supporting infrastructure (goal 9), stunted economy (goal 8), and limited purchasing power of the population (goal 1). These factors discourage telecommunication service providers (TSPs) from building expensive network infrastructure in locations where the potential to recuperate returns on huge capital expenditure (CAPEX) and operational expenditure (OPEX) is limited.

Therefore, it is important to reduce the factors affecting the total cost of ownership (TCO) for mobile network operators and mobile service providers, especially as there might be a mismatch between the requirements of the market and capabilities provided by network equipment. Telecommunication base stations (BS) are extremely expensive, running into thousands of USD. Beyond the cost element, it also takes several months for the necessary licence(s) to be approved. Table 1 summarises the primary cost estimation of acquiring a spectrum licence in South Africa (ZA). The actual cost of the spectrum blocks is not included because these are often auctioned to the highest bidder.

As an alternative to this expensive outlay, several solutions have been proposed to provide 5G network coverage to developing nations. These include beaming down Internet from the sky using balloons, as was the case with Google's Project Loon [10], or using hybrid networks, which utilize a combination of air-based unmanned aerial vehicles (UAVs) or drones with terrestrial-based communication radios to provide Internet. One such hybrid network was proposed in [11,12]. This work focuses on the hybrid network illustrated in

Figure 1 and discusses the economic viability of such a network in a developing country such as South Africa (ZA).

Table 1. Spectrum cost matrix.

Feature	Prices
Individual Application	ZAR 500,000 (USD 32,000)
Class Application	ZAR 12,187 (USD 790)
Renewal	ZAR 6094 (USD 380)
Amendment	ZAR 60,940 (USD 3800)
Uni Price per MHz	ZAR 2344 (USD 160)
Price per Block	Auctioned
Auction Investment	ZAR 25 Bn (USD 1.5 Bn)
Satellite Hub Station	ZAR 58,596 (USD 3700)

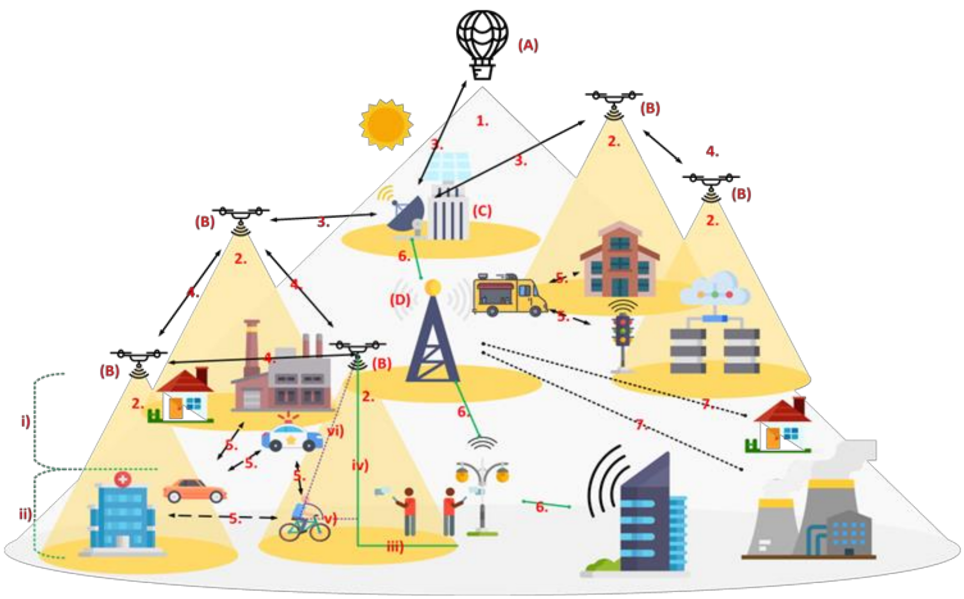


Figure 1. Hybrid 5G network. A = RRH-Balloon; B = RRH-UAV; 2 = UAV coverage area; C = terrestrial base station; D = cell tower; 1, 3, and 4 = backbone network; 5, 6, and 7 = wireless network [12].

In the hybrid network presented in Figure 1, three types of networks are considered to provide 5G coverage to rural areas. The first is by using UAVs, which relay Internet from terrestrial base stations over a coverage area. The second is through the use of cell towers, as is the case with mobile cellular networks; we refer to this as large cell (LC)-based. The third is by using wireless networks or Wi-Fi access points mounted in and around buildings; we refer to this as Hotspot.

The major contribution of this work is thus to determine if such a hybrid network is viable for providing 5G network access to rural dwelling areas of ZA. Thirteen locations were selected, viz., five district municipalities, four township areas, three rural residential areas, and one low-income town, with the expectation of:

- Determining the number of cell nodes required to effectively provide coverage in these locations as carried out in [13].
- Comparing the terrestrial networks (LC and Hotspot) to the aerial (UAV) network in terms of expenses and profitability for the TSP across all 13 locations.
- Revealing the optimal billing model (per gigabit or per minute) for users across the locations.

The remainder of this paper is as follows: Section 2 presents an overview of the economic model, including the description of the use cases. In Section 3, the economic feasibility analyses for both the capital and operation expenditures are presented, while the revenue analyses are conducted in Section 4. Section 5 then discusses the subscription fee required to sustain the model. Section 6 concludes the paper and gives some insights into future works.

2. Economic Model Foundation

Modern telecommunication systems have recently witnessed the convergence of cloud networking, fast connectivity, and high processing power taking place over the existing Internet model [14]. However, despite the gap between market requirements and network capabilities, there is still a significant absence of literature that caters to the rolling out of heterogeneous telecommunication technologies [14]. Frequently, researchers either concentrate solely on modelling the spatial viability aspect, as evidenced in the fixed broadband literature by [15], and/or on cost-effective radio network deployment such as in the work of [16]. It has been predicted that with the emerging heterogeneous 5G wireless network infrastructure, the administration of services and networks will be performed in an assembled way [17]. Hence, this works studies the total cost of ownership (CAPEX, OPEX, return on investment (ROI), internal rate of return (IRR), and the economic value added (EAV)) for deploying 5G basic wireless connections into rural and low-income areas of South Africa (ZA).

2.1. Assumptions and Scope

For this work, the following assumptions are made: (i). In computing the CAPEX, the costs of obtaining both the spectrum operating licence(s) and the Remote Operator's Certificate (ROC) for operating UAVs are not considered. This is due to the cumbersome process(es) involved, which cannot be directly modelled. (ii). For the aerial network, all UAVs are assumed to have autopilot functions, allowing them to hover over an area to supply coverage. Furthermore, they are equipped with energy-saving protocols for prolonged flight-times.

All cellular nodes have poor and limited connections to the public gateway base station. The economic framework considered in this study includes the cost of equipment and deployment scenarios that will enable the computation of CAPEX, OPEX, and the best monthly subscription fee. These financial and economic analyses are performed on 13 locations in ZA, which are split into five district municipalities, four townships, three rural residential areas, and one low-income town. For this work, we define a community as a cluster of individuals in the form of families living together, for a long time in a neighbourhood, while having mutual goals, interest, ways of life, and cultural norms. A rural community is thus an area under development and characterized as follows:

- Sparsely populated with clustered settlement.
- Residents are mostly involved in various forms of peasant agriculture with relatively low income. Recent statistics show that the average income of people living in rural areas is significantly lower than those in urban areas. For instance, in 2017, the average monthly income of a rural household in ZA was ZAR 2732 or USD 170 [18], while urban dwellers earned about ZAR 21,966 (USD 1442) [19].
- Rural communities experience slower development compared to urban areas because of the higher rate of illiteracy, smaller economy, and slower adaptation of modern technologies.
- Poor roads, mountainous landscapes, and few vehicles and transportation networks, all of which pose challenges to the installation and maintenance of cellular towers.
- Intermittent electricity supply from the grid makes it difficult to guarantee service quality in these areas, especially if the network equipment is powered by the grid.

2.2. Deployment Scenarios and Sites

As stated earlier, the economic analysis carried out in this study is performed to estimate the costs and possible revenue to be generated from deploying a hybrid 5G network architecture in certain areas of ZA, as well as the ideal monthly subscription fee for users in each location.

2.2.1. Demography

Table A1 gives a high-level description of the areas of interest in this work as extracted from the South African government's statistics website (Stats SA). It reveals that, on average, less than 10% of the young adult population has higher education and about 50% of them are unemployed. The table also reveals mining and agriculture as the prominent industries in these regions.

It is important to note that the values in Table A1 are simply used as a general guide and may not accurately reflect real-world conditions. For instance, in rural residential areas (such as Hlankomo and Gono'on'o), though the official statistics show that locations have an adequate electricity supply, physical visitation of the locations by the researcher reveals the complete opposite. There are no grid lines or electrical cables in these locations, and most homes have been without electricity for decades. A similar situation plays out in the Lulekani and Duduza township areas, with the exception being that most homes are visibly illegally connected to the electricity grid.

Municipalities

As stated earlier, five district municipalities are considered, namely Chris Hani in the Eastern Cape, Mopani, Vhembe, and Waterberg in Limpopo province, and Frances Baard in the Northern province. Figure 2 depicts the locations of these municipalities, as extracted from Google Maps. Chris Hani District Municipality is a Category C municipality situated in the north-eastern part of the Eastern Cape. It is the second-largest district, linking to all regions in the province. The municipality makes up six local municipalities, namely: Inxuba Yethemba, Intsika Yethu, Engcobo, Sakhisizwe, Enoch Mgijima, and Emalahleni. The Mopani District Municipality is found within the north-eastern quadrant of the Limpopo province. The district consists of five local municipalities: Ba-Phalaborwa, Greater Letaba, Greater Tzaneen, Maruleng, and Greater Giyani. Moreover, the Vhembe District Municipality is found in the northern part of the Limpopo province. It shares borders with Zimbabwe and Botswana in the north-west and Mozambique in the south-east through the Kruger National Park. It is made up of four local municipalities: Thulamela, Musina, Makhado, and Collins Chabane. The Waterberg District Municipality is a located in the western part of the Limpopo province. The municipality is the biggest district in the province, sharing its five-border control points with Botswana. It is comprised of five local municipalities: Bela-Bela, Modimolle-Mookgophong, Mogalakwena, Thabazimbi, and Lephalale. Another Category C municipality, Frances Baard District Municipality is a located in the far eastern part of the Northern Cape province. The municipality is the smallest district in the Northern Cape, accommodating the largest proportion of the province's population. It comprises the four local municipalities of Dikgatlong, Phokwane, Magareng, and Sol Plaatje.

Townships and Low-Income Areas

The four townships considered in this work are Soweto and Duduza (in Gauteng province), Khayelitsha (in Western Cape province), and Lulekani (in Limpopo province), while the low-income area was Zeerust (in North West province).

Soweto and Khayelitsha are low-income highly populated areas. Soweto has approximately 1,271,628 inhabitants and an average population density (user density) of 6400 people per square kilometre (users/km^2) [20]. Khayelitsha has a population of 391,749 inhabitants and an average of 10,000 people per square kilometre (users/km^2). The digital population statistics in ZA projects that about 80 of all Internet access will be through mobile phones in 2023 [21]; hence, for this study, we assume a modest 80% of the population in Soweto and Khayelitsha as active users of the Internet due to their proximity to Johannesburg and Cape Town, which are the two major economic hubs of ZA. Similarly, we propose an average downlink throughput of about 100 Mbps per user in these towns.

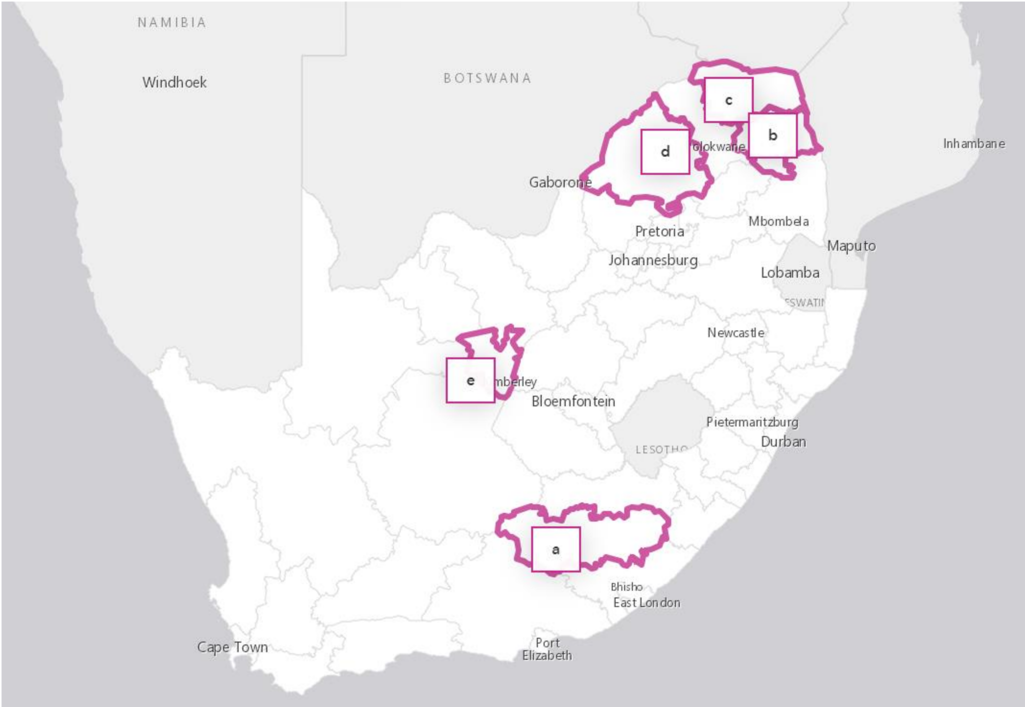


Figure 2. Map of District Municipality Areas: (**a**) Chris Hani; (**b**) Mopani; (**c**) Vhembe; (**d**) Waterberg; (**e**) Frances Baard.

Lulekani and Duduza are the two other township areas considered. Most areas within these towns do not have electricity, with only a few places illegally connected to the electricity grid. For these areas, the deployed network will have to rely mainly on solar power and batteries. We assume a download throughput of at least 50 Mbps for these areas, and about 60–80% of the population would have access to the Internet and use wireless communications. Zeerust is a small commercial town in North West province with approximately 9093 inhabitants. The main economy is based on cattle, wheat, maize, tobacco, and citrus fruit farming, as well as fluorite and chromite mining. It has an average user density of 160 users/km^2.

Rural Residential Areas

Hlankomo and Mandileni are rural residential areas in the Eastern Cape. Both have about 200 households and a population of approximately 1200 people each. Only 2% of these households have access to potable water within their dwellings. Gon'on'o is a village in Limpopo with similar characteristics to the two other areas. These three villages are not connected to the national electricity grids; hence, deployed 5G cells will have to be powered by solar panels and batteries.

2.2.2. Climate

Though there are numerous climatic conditions across ZA, and these climates can generally be grouped into three major categories, namely, arid, equatorial, and tropical [22]. Figure 3 shows a climate map, with the 13 locations of interest indicated. From the map, Frances Baard (F), Gon'on'o (G), Khayelitsha (K), Lulekani (L), Mopani (O), Vhembe (V), Waterberg (W), and Zeerust (Z) are in the arid regions, while Chris Hani (C), Duduza (D), Hlankomo (H), Mandileni (M), and Soweto (S) are in the tropical regions. Both the arid and tropical regions receive about 70% sunshine throughout the year, as shown in Figure 4. This makes them ideal locations for implementing the proposed hybrid 5G network.

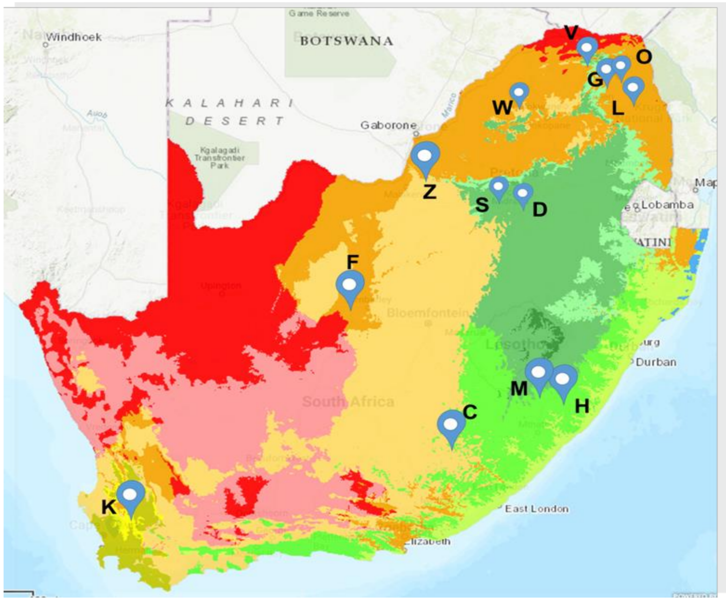


Figure 3. Climatic regions of ZA.

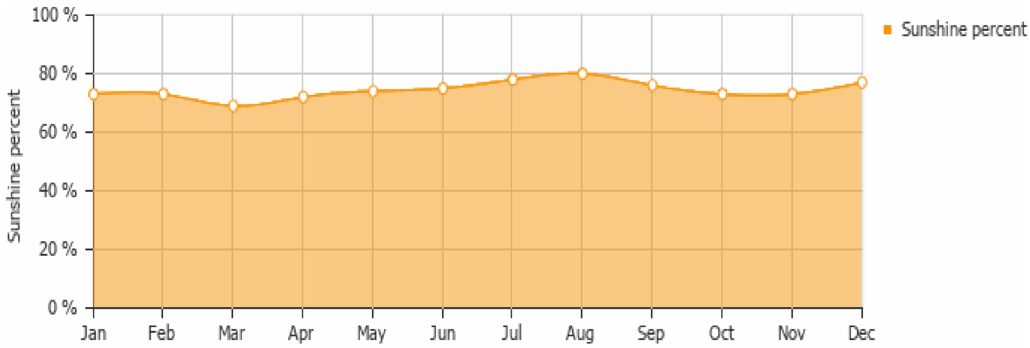


Figure 4. Average percentage of sunshine in specific regions of ZA [23].

2.2.3. Parameters Set over the Different Scenarios

Table A2 describes a detailed set of parameters for the different deployment scenarios. The lack of power grids in rural areas contributes to fewer people having devices that can access wireless networks. Hlankomo and Mandileni have a 30% active user ratio due to lack of electricity, while in sharp contrast, Duduza in Gauteng (an area also without legal connection to the electricity grid) has a higher active user ratio of 80%.

3. Economic Feasibility Objectives

The commercial feasibility analysis consists of determining the financial investments required for the implementation of the proposed network architecture in rural areas and if a sufficient return on investment can be obtained in the shortest period. Starting a new business can be extremely costly; hence, it is crucial to have a business plan that analyses the CAPEX needed to obtain necessities and implement the services to be offered. Likewise, to determine the IRR (internal rate of returns), the daily operational cost must be known. This section estimates both CAPEX and OPEX for deploying the proposed hybrid 5G network across 13 different locations in South Africa, as well as the computation of the minimum monthly subscription fees that will yield an ideal IRR for each deployment scenario.

Table 2 discusses the essential tangible and intangible requirements that form the basis of this analysis. The analysis excludes marketing and brand awareness expenses. Three network types (UAV, LC, and Hotspot) are considered for providing 5G as described in the introductory section. The goal of this analysis is mainly to provide information on the benefits that the initial expenditure will bring and prove to service providers that investing in a rural area can be beneficial. The computations of the CAPEX, OPEX, IRR, and subscription fees for all scenarios were performed using Microsoft Excel and the Python programming language.

Table 2. Fifth generation network node features [24].

Feature	Symbol	Description	UAV-Based	LC-Based	Hotspot-Based
Lifetime	L	Average time before disposal.	5 years	10 years	5 years
Cell Radius	R	Maximum cell range.	0.5 km	10 km	0.5 km
Peak Capacity	γ	Maximum capacity available to users. We assume a maximum downlink throughput T^{MAX} = 100 Mbps.	4.2 Gbps	12.6 Gbps	67.2 Gbps
Max. Power	P^{MAX}	Maximum power consumed when the maximum available capacity to users is being utilized.	1.4 kW	3.5 kW	5.6 kW
Min. Power	P^{MIN}	Minimum power consumed when the node does not serve any user (20% of the maximum node power).	0.28 kW	0.88 kW	0.28 kW
Battery Cost	C_B	Cost of a lead-acid battery with 12 V and 200 Ah generating 2.4 kWh.		R2.2 k/battery	
Solar Panel Cost	C_{SP}	Cost for a standard module type, size 1 kWp, system losses 14%, tilt 20, azimuth 180, DC to AC size ratio 1.1, inverter efficiency 96%, ground coverage ratio 0.4.		R11.55 k/battery	
Computing HW Cost	C_{CHW}	Cost of high-level computing hardware (HW) and networking of the virtual functionalities.	R144.4 k	R433 k	R 144.4 k
Radio HW Cost	C_{RHW}	Cost of the Remote Radio Head (RRH) and interconnection between them.	R144.4 k	R938.2 k	R 39.5 k
UAV Cost	C_{UAV}	Cost for rotary-wing quadcopter with 5kg payload.	R62.1 k	-	-
Site Acquisition Cost	C_{SA}	The total site acquisition cost mainly depends on the cell type, the cost to connect the site to the electricity network (if available), and the cost to build an access road up to the cell location.			
Spectrum Licence Cost	C_{SL}	Cost for spectrum licensing.			
Node Maintenance Cost	C_M	The yearly cost of inspection, solar panel cleaning, and software updates.	R5.1 k/year	R7.65 k/year	R 2.55 k/year

3.1. Capital Expenditure

The capital expenditure (CAPEX) is the foundational business cost that creates future benefits. This includes the cost of tangible assets concerning remote cell computing hardware, site acquisition, and UAVs. Additionally, analysis of the number of 5G nodes required for various deployment scenarios is considered. The possible number of base stations (BS) can be easily obtained using Equation (1), defined as:

$$N_{BS} = \frac{(1+m) * T^{MAX}}{c} \tag{1}$$

where T^{MAX} is the total peak throughput capacity per node, C is the average capacity supplied by microcell, and m is the ratio of connected margin to c. The number of 5G RRH-UAVs (N_c) required is obtained using Equation (2), defined as:

$$N_C = max(N_{C_{area}}, N_{C_{users}}) \tag{2}$$

where $N_{C_{area}}$ is based on the size of the area A of interest, defined by

$$N_{C_{area}} = \frac{2 \cdot A}{3\sqrt{3} \cdot R_c^2} \tag{3}$$

and $N_{C_{users}}$ is based on the number of active users N_u.

$$N_{C_{users}} = \frac{N_u \cdot \alpha \cdot T}{\gamma} \tag{4}$$

R_c is the radius of the hexagonal cell coverage area, A is the size of the prescribed area, N_U is the total number of users, α is the ratio of active users in the network, T is the average throughput per subscribed user, and γ is the peak capacity of the RRH network cell.

3.1.1. Nodes Comparison

Here, the number of nodes required for each scenario described in Table A2 for each network type is presented. The value is determined using three approaches, which are "Based on Max" (Equation (2)), "Based on Area" (Equation (3)), and "Based on Active Users" (Equation (4)). The number of cellular networks forms the basis of the entire CAPEX analysis. It also influences the OPEX because the cost of operation grows in proportion to the number of nodes required.

In Figure 5a,b, comparisons of the various deployment scenarios are shown. The figures show the possible number of 5G nodes required for all three network types, varied number of active users, area sizes (in square meters), and highest values. It can be seen from Figure 5a that covering each of the municipalities (Mopani, Vhembe, Waterberg, Chris Hani, and France Baard) requires a significantly higher number of nodes compared to the rural areas, as shown in Figure 5b.

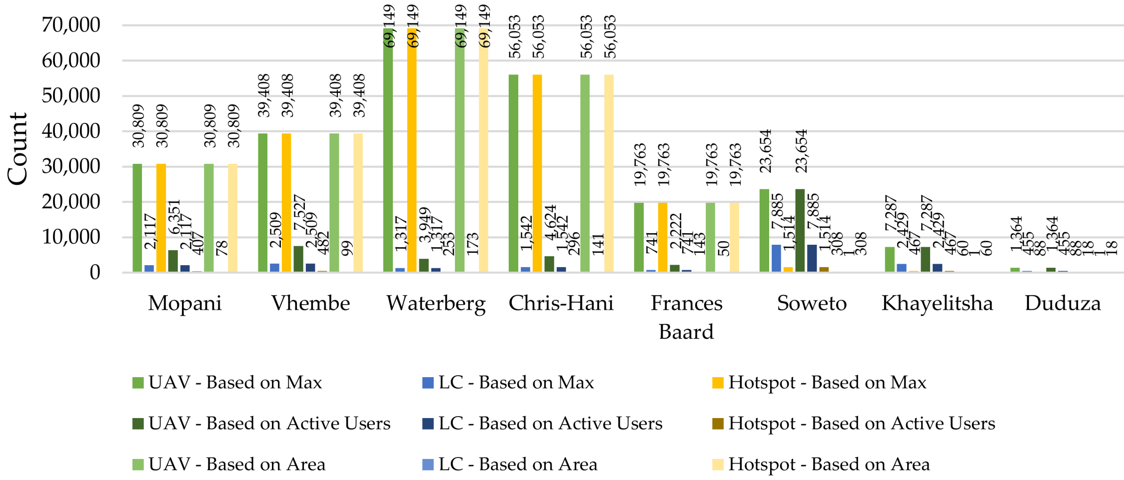
For the five municipalities, the area-based approach yields a higher value. Note that the "Based on Max" approach simply selects the higher value between the area-based approach and users-based approach and hence and would have the same value as the higher of the two. Though Soweto and Khayelitsha townships are smaller than the municipalities in area size, they have denser populations. This causes the user-based approach to be higher than the area-based approach, as depicted in the figure. Moreover, the two townships have a higher number of literates with access to cellular phones, the Internet, and multimedia, which also influences the higher value for the user-based approach.

3.1.2. Expense Analysis for Remote Access Network (RAN)

This sub-section discusses the CAPEX of three network types (UAV, LC, and Hotspot) over the same scenarios in Table A2. The total number of cell nodes obtained in the previous subsection is used in this CAPEX analysis. Equation (5) gives the total CAPEX needed to deploy a RAN using any of the network types.

$$CAPEX = N_C(C_B N_B + C_{SP} P_{SP} + C_{CHW} + C_{RHW} + C_{UAV} + C_{SA}) \tag{5}$$

Here, C_B is the cost of a single battery, N_B is the number of batteries per site, C_{SP} is the cost for one (kWp) of the solar panels, P_{SP} is the power of the solar panels per site, C_{CHW} is the cost of computing hardware, C_{RHW} is the radio hardware cost, C_{UAV} is the UAV cost, and C_{SA} is the site acquisition cost [24].



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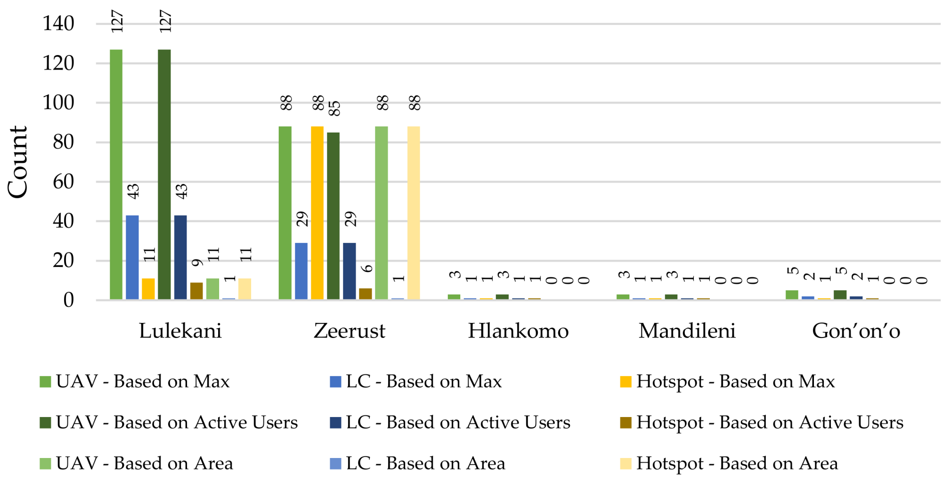


(**b**)

Figure 5. (**a**) Deployment for municipalities and township areas; (**b**) deployment for rural residential areas.

Based on the Number of End Users

Figure 6a–c depict the total CAPEX computed based on the number of users for the 13 locations. Each graph shows the cost of each parameter needed to deploy a network in South African rands. Interestingly, in each scenario, the UAV-based and Hotspot-based solutions consistently require more CAPEX than the LC-based solution. Across the board, the most substantial contributors to the costs are site acquisition and computing/radio hardware (HW) expenses, while the UAVs, solar panels, and batteries have a lower impact on the CAPEX. Of the municipalities, Vhembe has the highest number of users and hence the higher CAPEX; similarly, due to their dense populations, Soweto and Khayelitsha townships required much more CAPEX than the other township areas.

Based on Area Size

The CAPEX breakdown bar graphs in Figure 7 show the expenses of each scenario based on location size. Costs are directly proportional to the size of the targeted areas; hence, the five districts have significantly higher expenses compared to the other locations. The figures also show that due to the coverage area, the UAV-based and Hotspot-based solutions need greater CAPEX than the LC-based solution. This is because both models need more cell nodes to cover the entire area compared to LC, which only requires a few (possibly only one) nodes. Across the locations, site acquisition accounts for more than half of the entire CAPEX.

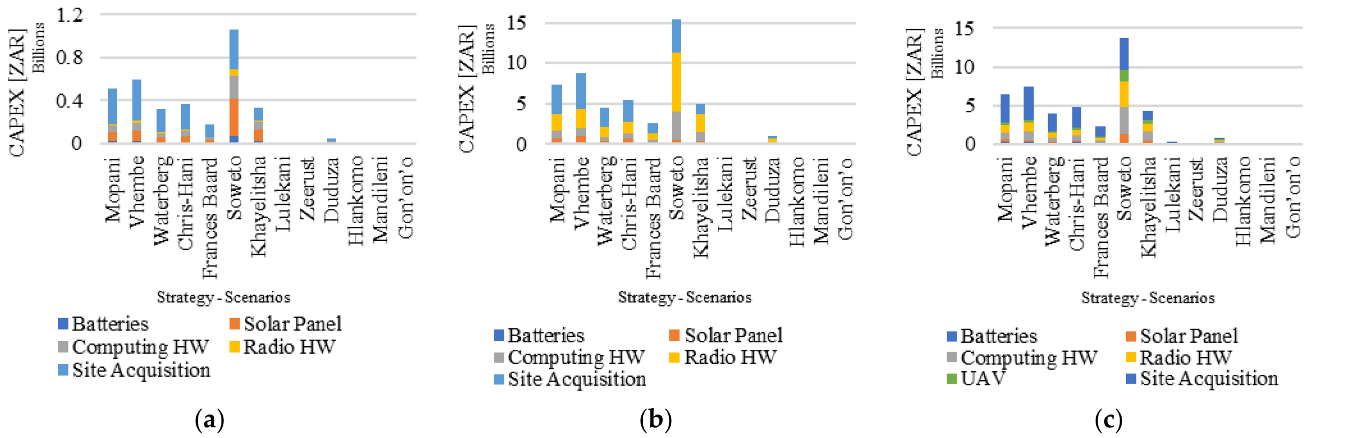


Figure 6. CAPEX breakdown based on the number of active users for each network type: (**a**) LC-based; (**b**) Hotspot-based; (**c**) UAV-based.

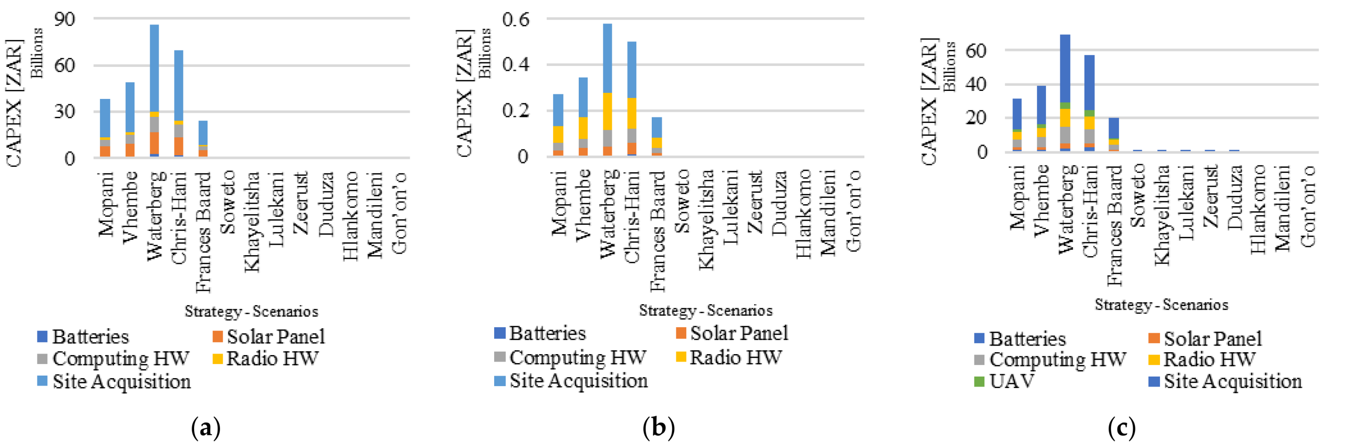
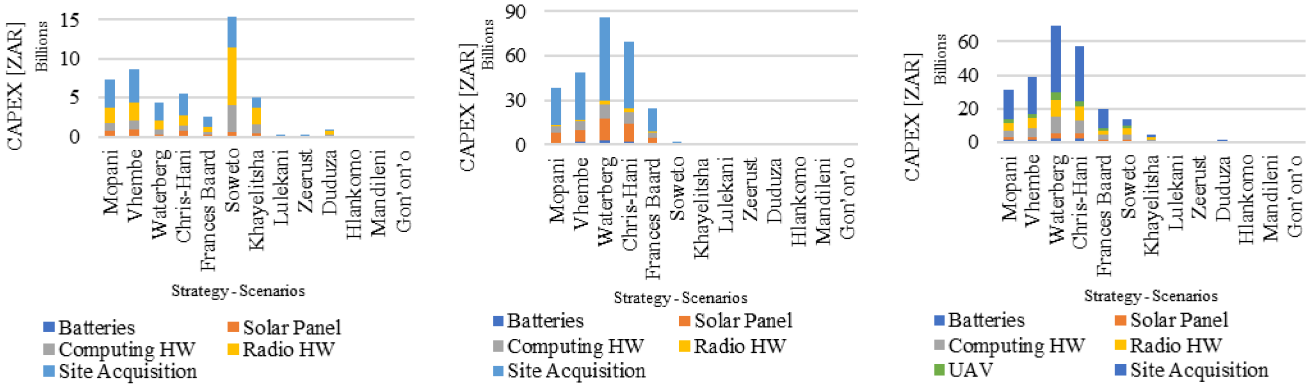


Figure 7. CAPEX breakdown based on area size for each network type: (**a**) LC-based; (**b**) Hotspot-based; (**c**) UAV-based.

Based on the Highest Number of Cells

Figure 8 presents the expenditures of each scenario by showing the analysis for RAN. Like the first two cases, the UAV-based and Hotspot-based solutions need greater CAPEX compared to the LC-based. However, in this analysis, the size of the scenario has a greater impact on the CAPEX, with the expenditure being significantly higher for the district municipalities.

For the rural residential areas, a single LC-based solution can supply basic network services over most of the considered areas. Looking closer at these zones, Gon'on'o requires five UAVs, two LCs, or a single Hotspot-based cellular node to provide full coverage to the village, while Mandileni and Hlankomo require either three UAVs, one LC, or one Hotspot-based cell. Though Gon'on'o is a small residential area, it needs more nodes than the other rural residential areas because there are more people who live there.



(**a**) (**b**) (**c**)

Figure 8. CAPEX breakdown based on highest number of cells: (**a**) LC-based; (**b**) Hotspot-based; (**c**) UAV-based.

For the townships, in the LC-based solution (Figure 8a), Soweto township has the highest CAPEX over all other scenarios because of its vast population density. Conversely, Mopani, Vhembe, Waterberg, Chris Hani, and Frances Baard municipalities have the highest CAPEX in the Hotspot-based (Figure 8b) and UAV-based (Figure 8c) solutions due to their immense area size. Despite the dense population of the townships, the UAV-based or Hotspot-based solution costs less. Computing and radio *HW* cost slightly more in the LC-based solution because the targeted scenarios have a vast area that requires many cells to have full coverage. Contrarily, they cost less in UAV-based and Hotspot-based solutions due to the coverage range of a single cellular unit. A considerably large area requires more cells, which in return contributes extensively to site acquisition expenses.

3.2. Operational Expenditure

Operational expenditure (OPEX) refers to costs incurred while operating the 5G network. It includes but is not limited to maintenance and administrative expenses. Other expenses, such as insurance, depreciation, and interest, are not considered in our OPEX calculation. For brevity, only the OPEX required to run the highest number of cells is shown, as this depicts the maximum expenditure. Equation (6) is used to compute the OPEX for an entire year:

$$OPEX_i = N_C\left[365\cdot\left(\sum_h * P_h * C_E\right) + C_M\right] \tag{6}$$

where N_c is the number of deployed network cell nodes, which in this case refers to Equation (2), P_h is the power required from the electricity grid by the site at hour h, C_E is the cost for one kilowatt-hour (kWh) of energy, and C_M is the maintenance cost.

The line graph in Figure 9 depicts the expenses required to supply 5G network coverage for a year over the 13 selected locations using the three network types. In all scenarios, the LC-based network cost less than the others to operate. However, when using the LC network, Soweto township still required an OPEX of about ZAR 90 million (USD 5.7 m) annually, compared to the other locations with ZAR 30 million (USD 1.9 m) at most.

For the five municipalities, the Hotspot- and UAV-based systems cost significantly more to run than the LC-based model. Waterberg and Chris Hani have the largest area expanse and hence the priciest scenarios to run both network types. On the contrary, though Soweto has the smallest area compared to the district municipalities, it is expensive to run the UAV-based network there because of its huge population density. The low-income town and rural residential areas have the lowest OPEX of all network types due to their small area sizes and low population. These areas thus require fewer cells for coverage. The maximum OPEX for Lulekani, Zeerust, Duduza, Hlankomo, Mandileni, and Gon'on'o is ZAR 0.5 m (USD 0.32 m), irrespective of the cells deployed.

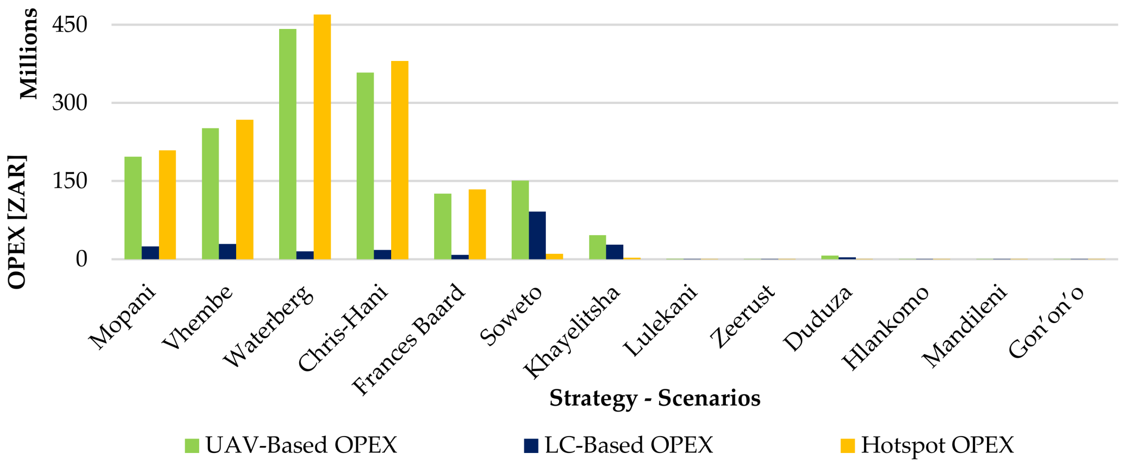


Figure 9. Operating expenditure over selected scenario.

4. Revenues over Time

This section analyses the return on investment (ROI) for deploying the proposed hybrid 5G network in some of the currently disadvantaged ZA areas. The standard statistical profitability ratio helps to determine the loss or profit obtained in each network type for the total CAPEX. Figure 10 depicts censors and generalized regional service charges for users over targeted scenarios. This revenue calculation assumes that the number of users remains relatively constant and that users pay their subscription fees monthly.

Figure 10. Population and service charge over scenarios.

The revenue (REV) is the income generated from network coverage service operations including discounts and network sharing, while cash flow (CF) is the net amount of money that moves into and out of a business. Furthermore, the IRR discount rate estimates the overall profitability of potential investments during CAPEX budgeting. It makes the net present value (NPV) of all CF from a network deployment project to be equal to zero. Moreover, IRR computations depend on the same formula as the NPV, with some slight adjustments.

4.1. Revenue Analysis

The yearly revenue (REV_i) forecasts profits to be made throughout the expected lifetime of the cell over the chosen areas, where i is the number of years, assuming each user pays a monthly subscription fee F to use the network. Equation (7) can thus be used to calculate income based on this constant monthly subscription.

$$REV_i = N_U \cdot 12 \cdot F \tag{7}$$

Figure 11 shows a line graph for the annual income of all network types. From a glance, all five district municipalities generate more revenue compared to rural residential areas and townships, while the France Baard region is the lowest producer, generating approximately ZAR 2b (USD 126 m) of income. Vhembe district municipality and Soweto township both have a vast population and as expected also have considerably higher revenue per year. Though Vhembe has the highest revenue, it is only marginally higher than Soweto, due to its lower average population density when compared to Soweto (see Table A2). Finally, for the rural residential areas, only about half a billion ZAR (USD 33 m) is attainable at most as revenue.

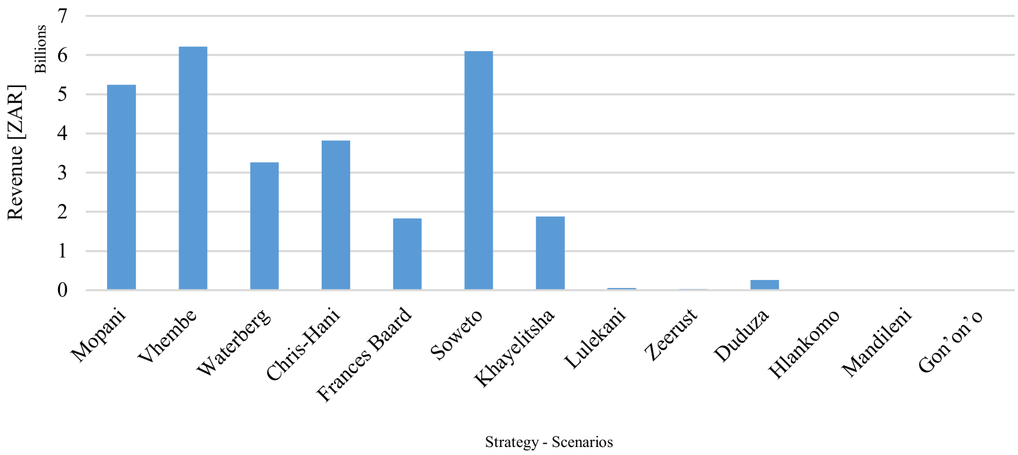


Figure 11. Revenue over selected scenario.

4.2. Cash Flows Analysis

With the revenue and expenditure obtained in the previous sections, the cash flow analysis can then be done. The expression in Equation (8) is for obtaining the operators' annual net cash flows (CF_i), where i is a specific year during the network operation, and l is the lifetime of the solution in years.

$$\begin{array}{c} -OPEX\ for\ year\ i = 0 \\ CF_i = REV_i - OPEX_i\ for\ year\ 0 < i < l \end{array} \tag{8}$$

At the inception (first year, where $i = 0$), we simply subtract the OPEX for that year. CF_i represents the profit or loss value of the network operator during a specific period.

Given the requisite knowledge of CF_i, it is important to first determine if the revenues can compensate the CAPEX and OPEX, by computing the net present value (NPV). Specifically, by definition, NPV is the summation of cash flows CF_i over the entire lifetime, each normalised by $(1 + \eta)$, where η is the discount rate, i.e., the return (in percentage), that could be earned with an ideal financial investment (such as bank funding, loans, etc.) [11]. Equation (9) adopted from [25] is used to calculate the NPV:

$$NPV = \sum_{i=1}^{L} \frac{CF_i}{(1+\eta)^i} - CF_0 \tag{9}$$

where CF_0 is the total first investment expense, and i is the period (in years).

The analysis starts with a current balance and produces a closing balance sheet after accounting for all cash inflows and outflows during the period. Using the monthly subscription fee (shown in Figure 10), the computed OPEX (using Equation (6)) and annual revenue (computed using Equation (7)), for the same scenario parameters on Table A2, the NPV can be calculated using Equation (9). The clustered column bar graph in Figure 12 depicts the NPV for the three network types.

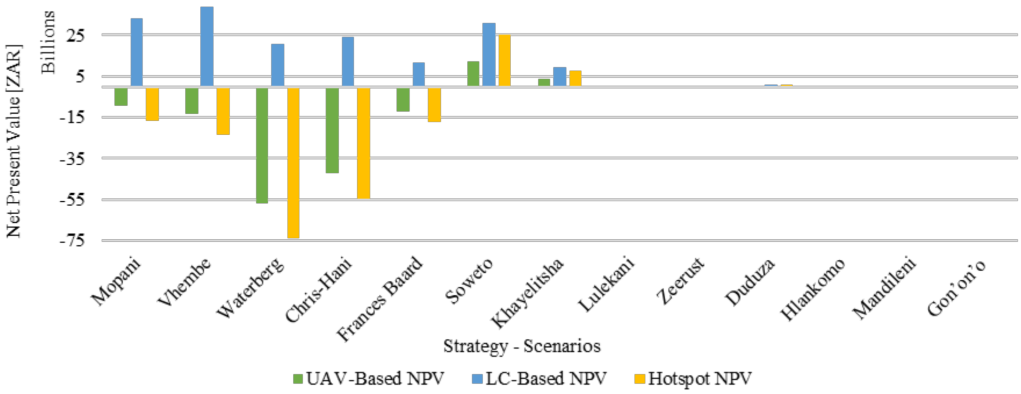


Figure 12. Net present value over selected scenario.

Interestingly, in each scenario, the LC-based solution with the proposed monthly subscription fee in Figure 10 yields a more profitable return than both the UAV- and Hotspot-based solutions. Hence, by using only UAV- and Hotspot-based solutions to supply 5G services to any district municipalities, the operator will not be able to recover the initial CAPEX. For instance, Waterberg region requires more than ZAR 55 B (USD 3.7 B) for both UAV- and Hotspot-based solutions to run until their lifetime expires, but it only generates about ZAR 3B (USD 200 m) (see Figure 11). In the case of Vhembe, due to its larger population compared to the other municipalities, it requires more SCs to fully supply coverage to the entire area and hence more expenditure. To this end, only the LC-based solution is more profitable in the district municipalities. On the contrary, the low-income and rural residential areas are profitable for all network type, with Soweto and Khayelitsha townships yielding the highest cash flows.

4.3. Internal Rate of Returns

The internal rate of return (IRR) is a measure of an investment's rate of return. The term "internal refers" to the fact that the calculation excludes external factors, such as the risk-free rate, inflation, the cost of capital, or various financial risks. To calculate the IRR, we set Equation (9) to zero and solved for the discount rate η (IRR) using the other values given.

The graphs in Figure 13 depict IRR for the three model solutions being considered over the 13 ZA locations. The LC-based solutions (Figure 13a) would require users to pay close to a ZAR 1,860 (USD 127) monthly subscription fee to obtain at least 10% IRR across all locations. When UAVs are used, Figure 13c reveals that with about ZAR 200 (USD 13), an IRR of 10% can be obtained across all locations. Finally, the Hotspot-based solution (Figure 13b) would require users to pay almost ZAR 1838 (USD 116) for a 10% IRR. In essence, by using UAVs, with a monthly subscription fee of just ZAR 30 (USD 2), a 50% IRR can be obtained in the rural areas or ZAR 200 (USD 13) for profitability across all locations.

$$F = \frac{NPV + NPO + C_0}{NPP_{N_U}} \tag{10}$$

Here, *NPO* is the net present operational expenditure obtained using Equation (11), and *NPP* is the net present payment per user, calculated using Equation (12).

$$NPO = \sum_{i=1}^{L} \frac{OPEX_i}{(1+\eta)^i} \tag{11}$$

$$NPP = \sum_{i=1}^{L} \frac{N_U \cdot 12}{(1+\eta)^i} \tag{12}$$

Equation (12) yields the best monthly subscription fee, which is then used to obtain the IRR graph in Figure 14. A rate (η) of 30% was used to yield the subscription fee over the selected scenarios. The graph reveals that township areas such as Soweto, Khayelitsha, and Duduza have more potential for lucrative growth than any of the municipalities, while rural residential areas require less than ZAR 50 to yield a 100% IRR.

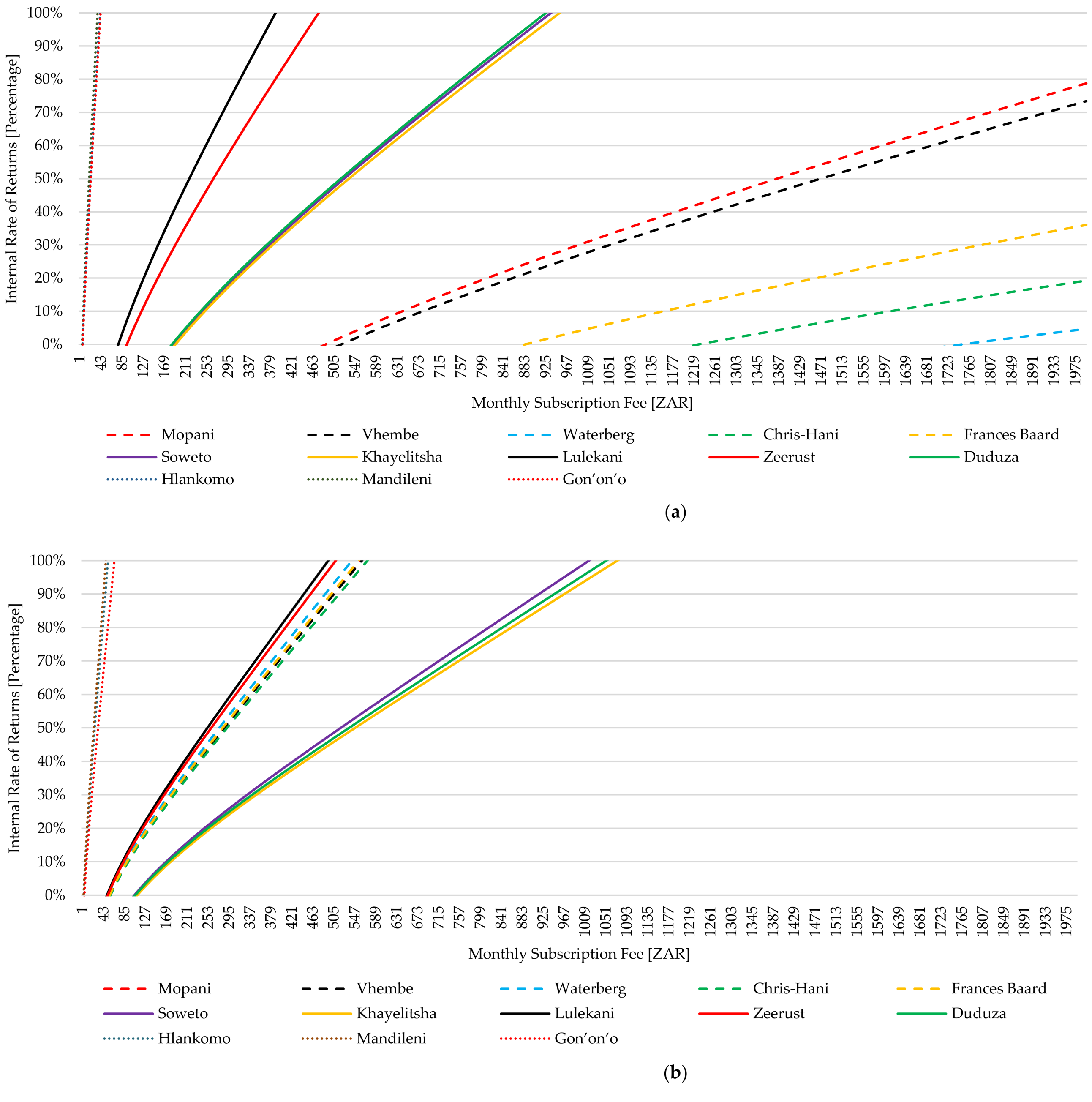
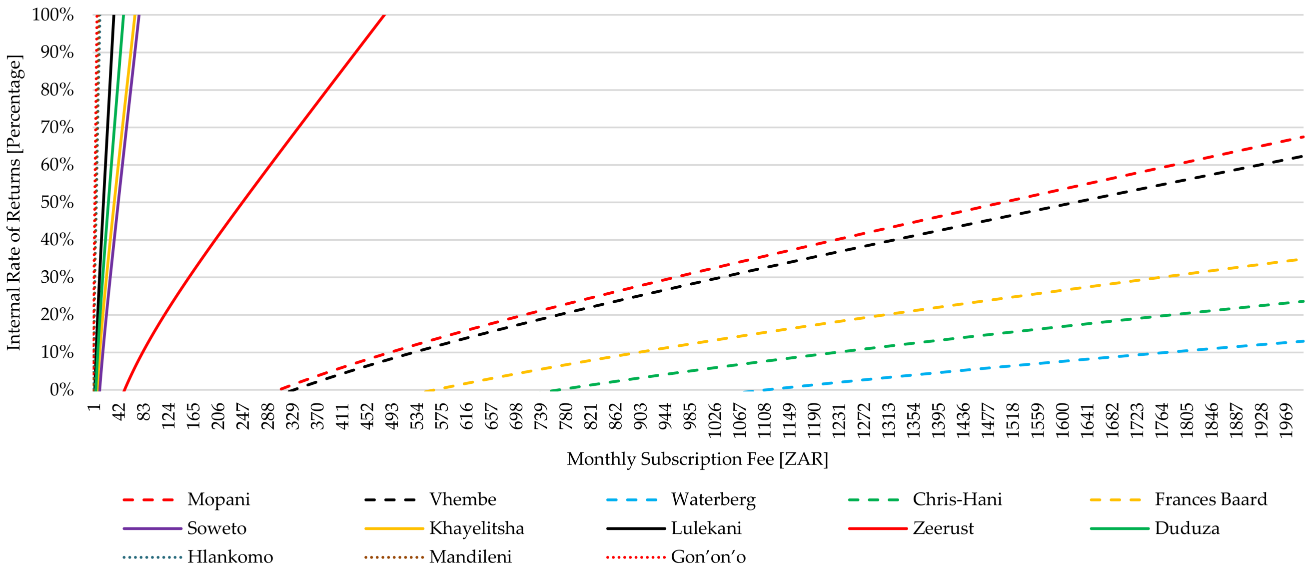


Figure 13. *Cont.*



(**c**)

Figure 13. Internal rate of returns over the considered scenarios: (**a**) LC-based; (**b**) Hotspot-based; (**c**) UAV-based.

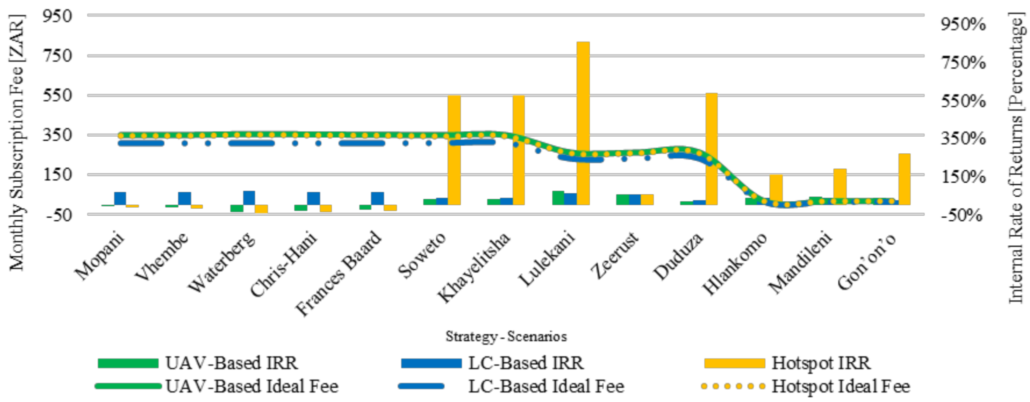


Figure 14. Internal rate of return based on monthly subscription fee over selected scenario.

5. End-User Subscription Fee

In an article published by Fin24, it was claimed that the South African telecommunication services providers MTN and Vodacom charged up to 2639% more for out-of-bundle data. It was also reported that while on contract, a Vodacom 20 GB data bundle costs ZAR 329 (USD 20.75) or ZAR 0.02 per megabyte, while for out-of-bundles the rate per megabyte was ZAR 0.44 (USD 0.03) [26]. This is an estimate of about 2630% higher for out-bundle than in-bundle. Similarly, MTN's 25 GB prepaid bundle costs ZAR 1250 (USD 79) or ZAR 0.05 per megabyte, while the out-of-bundle package cost ZAR 0.99 (USD 0.06) per megabyte. This represents a 1928% difference between in and out-of-bundle charges. Data bundle prices for major operators in ZA are compared in Table 3, with monthly data usage estimated from the Verizon Wireless website.

Table 3. Data bundle price comparison across ZA telecommunication service providers.

	Usage	Size (GB/Month)	Price (ZAR)			
			Vodacom [1]	Telkom [2]	MTN [3]	Cell-C [4]
e-Mail (Text only)	7500 (e-Mail)	0.07	R29			
Web Access	7500 (pages)	10.99	R748	R598	R648	R748
Stream Music	60 (h)	3.52	R399	R275.25	R398	
Stream HD Video	15 (h)	30	R1 598	R1 398	R1 249	R899
Stream SD Video	30 (h)	19.04	R999	R899		R799
Upload and Download Photos	3000 (photos)	14.65	R999	R798	R899	R799
4G VoIP	60 (h)	2.64	R299	R199	R378	R299
4G VoIP with Video	60 (h)	15.23	R999	R837	R899	R799

[1] http://www.vodacom.co.za/vodacom/shopping/data/prepaid-data, (accessed on 18 September 2022); [2] https://secure.telkom.co.za/today/shop/personal/plan/100-gb-data-bundles/, (accessed on 19 September 2022); [3] https://www.mtn.co.za/Pages/MTNDataBundle.aspx (accessed on 18 September 2022); [4] https://www.cellc.co.za/cellc/bundles-contract-detail/DataBundles#/sku6850032, (accessed on 18 September 2022).

5.1. Monthly Subscription Fee

This section compares the average monthly subscription fees for uncapped data users (as at the time of writing) versus prepaid users. Figure 15 depicts uncapped subscription fees for five TSPs in ZA versus the proposed average monthly fee (ZAR 282 or USD 18) from the analysis of our hybrid 5G network.

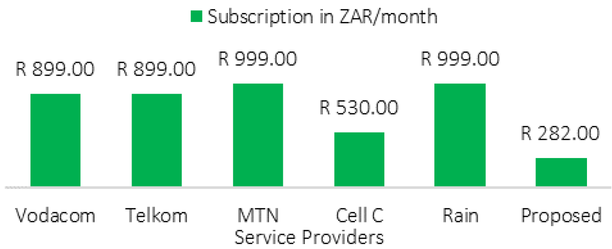


Figure 15. Monthly subscription fee comparison.

5.2. Capped Subscription Fee

A gigabit (Gb) is a unit measurement of digital storage that is based on binary multiples of bits, while a megabyte is based on binary multiples of bytes with MB being a standard symbol. There are 128 megabytes in a gigabit; hence, a transfer rate of 1 Gb/s is equal to 125 MB/s. Table 4 shows the estimated daily transfer capacity of different cells based on the sinusoidal function of power consumption given in Table 2. Equations (13) and (14) are used to obtain the prepaid subscription fees "per GB" and "per minute", respectively. These fees are inclusive of mandatory tax(es).

$$P_{GB} = \frac{N_c \cdot F}{\omega \cdot \alpha \cdot \beta} + Tax \tag{13}$$

$$P_t = \frac{N_c \cdot F}{t \cdot \alpha \cdot \beta} + Tax \tag{14}$$

The line graphs in Figure 16 depict the prepaid price for the three network types considered over the selected scenarios. The price modelling framework is based on Figure 14 and Equations (13) and (14), where t is time in minutes. Furthermore, the expression considers the probability of active users on the network and how long each user will be active. Both costs "per minute" and "per GB" graphs have different charge curves as shown in Figures 16 and 17. Overall, rates per GB are more expensive than per minute rates.

Table 4. Estimated daily data transfer.

	Symbol	UAV-Based	LC-Based	Hotspot
Peak Capacity	γ^{MAX}	15.12 Tb/h	45.36 Tb/h	241.92 Tb/h
Min. Capacity	γ^{MIN}	3.024 Tb/h	9.072 Tb/h	48.384 Tb/h
Mid. Capacity	m	6.048 Tb/h	18.144 Tb/h	96.768 Tb/h
Traffic per Day	ω	27.216 TB	81.648 TB	435.456 TB

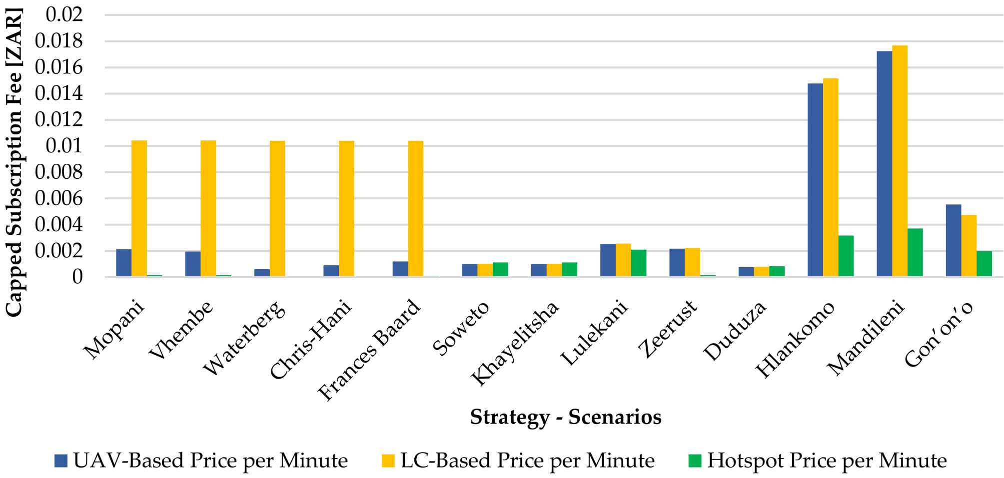


Figure 16. Capped User Subscription Fee—Per Minute.

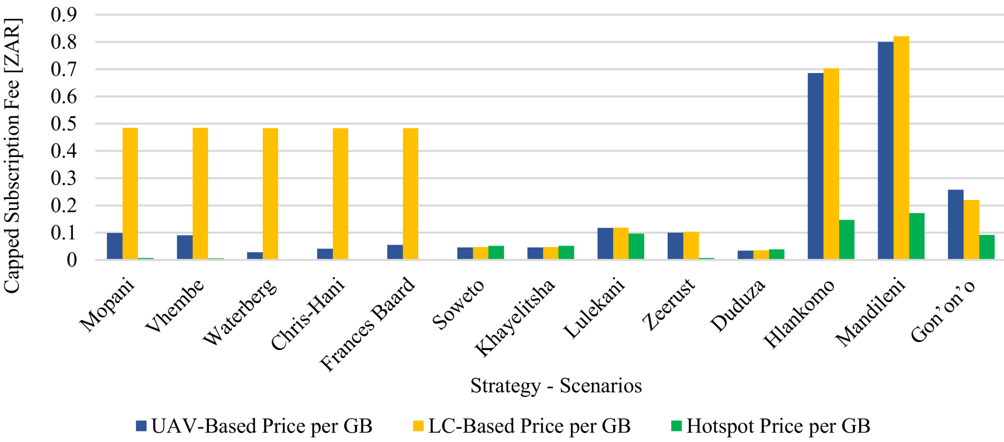


Figure 17. Capped user subscription fee (per GB).

The graphs reveal that the rural residential areas of Hlankomo and Mandileni would pay the most for all network types and significantly more for the LC- and UAV-based solutions. On the contrary, the users in the township areas pay the least across all network types, while the municipalities are charged about an average of the rural and township prices. Despite these values, it is important to note that our average proposed price for all three network types (UAV-, LC-, and Hotspot-based network) is ZAR 0.50 (USD 0.031) for 1 GB of data bundles. Even at a peak rate of ZAR 0.80 (USD 0.05), our proposed hybrid network is still extremely cheaper compared to other TSP rates, such as Telkom, which charges ZAR 60.00 (USD 3.8) or Cell C with a rate of ZAR 75.66 (USD 4.8) for 1 GB of data bundles.

6. Conclusions

The objective of this paper was to determine whether it is economically feasible to deploy a hybrid 5G network in rural areas, which uses cellular nodes (mounted on an unmanned aerial vehicle) to beam network coverage from the sky to users, while piggybacking on terrestrial cellular nodes. This network was to be deployed to serve as an enabler in achieving the sustainable development goals, including providing good health care, reducing poverty, and improving infrastructural development in less developed areas of the world. Thirteen locations were selected in South Africa, including five district municipalities, four township areas, three rural residential areas, and one low-income area. Three scenarios were considered per location, using three network types: UAV-based, Hotspot-based, and LC-based. In performing the analysis, the capital expenditure (CAPEX), operation expenditure (OPEX), internal rate of return (IRR), return on investment (ROI), and power requirements were considered. All of which were used to obtain the recommended monthly user subscription fees for Internet access per GB and per minute.

From the analysis, it can be concluded that it is more expensive to deploy the proposed hybrid 5G coverage in large but sparsely populated areas. For such areas, the traditional LC-based system is more profitable. On the contrary, implementing the hybrid architecture in rural residential areas costs less and yields higher revenue than low-income areas. The analysis also reveals that with the proposed model, the best monthly subscription fee will cost far less than the current data bundle prices being offered by telecommunications providers in South Africa.

It is important to note that this work did not consider several factors such as cost of acquiring the spectrum licence, cost of site constructions, electricity grid tariffs, staff salaries, depreciation, etc. These factors are vital and can impact the overall performance of the proposed network. Incorporating these factors might be one avenue of extending this work in future. In the same vein, various models for the optimal placement of UAVs to maximize network coverage could also be considered for future works.

Author Contributions: Conceptualization, A.B. and L.C.; methodology, H.M. and A.B.; software, H.M.; validation, A.B. and O.A.; formal analysis, O.A. and A.B.; investigation, H.M.; resources, L.C. and A.B.; data curation, H.M..; writing—original draft preparation, H.M.; writing—review and editing, O.A. and A.B.; visualization, H.M.; supervision, A.B. and O.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Demography of the 13 regions considered (adapted from [27]).

Parameters	Scenario												
	Mopani	**Vhembe**	**Waterberg**	**Chris Hani**	**Frances Baard**	**Soweto**	**Khayelitsha**	**Lulekani**	**Duduza**	**Zeerust**	**Hlankomo**	**Mandileni**	**Gon'on'o**
	District	**District**	**District**	**District**	**District**	**Township**	**Township**	**Township**	**Township**	**Low-Income**	**Rural Residential**	**Rural Residential**	**Rural Residential**
Municipality						City of Johannesburg	City of Cape Town	Ba-Phala borwa	City of Ekurhuleni	Ramotshere Moiloa	Ntabankulu		Greater Giyani
Main Economic Sectors	Mining (30.1%) Community Services (22.6%) Trade (14.6%) Finance (14.6%) Transport (8.2%) Agriculture (3.2%) Electricity (2.8%) Construction (2%)	Mining Community services Finance	Mining Agriculture Tourism	Community Services (52%) Trade (15%) Finance (14%) Transport (6%) Agriculture (4%) Manufacturing (4%) Electricity (2%)	Community services (28%) Finance (22%) Trade (15%) Transport (12%) Mining (10%) Agriculture (4%) Manufacturing (4%) Construction (3%) Electricity (2%)	Finance and business services, community services, manufacturing, trade (collectively 82%)	Finance and business services (36.1%), manufacturing (16.1%), trade and hospitality (15.6%), community services and general government (15.0%), transport, storage, and communication (11.2%), construction (4.1%), electricity (1.1%), agriculture (0.7%), mining (0.1%)	Mining, agriculture, manufacturing, tourism	Manufacturing (23%), finance and business services (21.3%), community services (20%), trade (15%), transport (11%), construction (4.1%), electricity (2.3%), mining (2.3%)		Agriculture, sand and quarry mining, forestry, tourism		Agriculture, tourism, retail, transport
Unemployment rate (Aged 15–34)	51.4%	~50.6% (Year 2011)		~60%	43.9% (Year 2011)	31.5 (Year 2011)	31.9 (Year 2011)	50.2%	28.8 (Year 2011)		53.7% (Year 2011)		61.2%
Higher Education (Aged 20+)	8.1%	9.6%	9%	6.5%	8.4%	14.7%	14.4%	9.2%	11.9%	5.8%	4.3%		8.5%
Piped water inside dwelling	12.8%	7.4%	24.4%	22.3%	48.4%	60%	76.7%	30.6%	56%	16.8%	1.1%		10.3%
Electricity	94.5%	94.6%	86.1%	89.9%	90.2%	90%	97.2%	98.1%	85.4%	88.6%	51%		92.5%
Sanitation	20.5%	20.9%		32.8%		86.2%	89.4%	20.5%	70.5%		2.0%		

Table A1. *Cont.*

Parameters	Scenario												
	Mopani	**Vhembe**	**Waterberg**	**Chris Hani**	**Frances Baard**	**Soweto**	**Khayelitsha**	**Lulekani**	**Duduza**	**Zeerust**	**Hlankomo**	**Mandileni**	**Gon'on'o**
	District	**District**	**District**	**District**	**District**	**Township**	**Township**	**Township**	**Township**	**Low-Income**	**Rural Residential**	**Rural Residential**	**Rural Residential**
Flush toilet connected to sewerage	14.1%	16%	43.8%	31.6%	78.4%	88.6%	91.0%	36.8%	88.4%	25.9%	0.5%		11.4%
Solid Waste Services	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No		No

Table A2. Parameters set over the different scenarios.

Parameter	Symbol	Scenario												
		Mopani	**Vhembe**	**Waterberg**	**Chris Hani**	**Frances Baard**	**Soweto**	**Khayelitsha**	**Lulekani**	**Zeerust**	**Duduza**	**Hlankomo**	**Mandileni**	**Gon'on'o**
Type	-	District	District	District	District	District	Township	Township	Township	Low-Income	Township	Rural Residential	Rural Residential	Rural Residential
Area Description	-	Category C Municipality located in Limpopo	Category C Municipality located in Limpopo	Category C Municipality located in Limpopo	Category C Municipality located in Eastern Cape	Category C Municipality located in Northern Cape	Next to Johannesburg	Next to Cape Town	Outside Phalaborwa in Limpopo	Commercial town situated in North West	A township west of Nigel on the East Rand	A village next to Qumbu and Mthatha in Eastern Cape	A village next to Mthatha in Eastern Cape	A village next to Giyani in Limpopo
Area Size	A	20,011 (km^2)	25,596 (km^2)	44,913 (km^2)	36,407 (km^2)	12,836 (km^2)	200.03 (km^2)	38.71 (km^2)	6.61 (km^2)	57.09 (km^2)	11.23 (km^2)	- (km^2)	- (km^2)	- (km^2)
Average Density	δ	55 ($users/km^2$)	51 ($users/km^2$)	15 ($users/km^2$)	22 ($users/km^2$)	30 ($users/km^2$)	6400 ($users/km^2$)	10,000 ($users/km^2$)	2200 ($users/km^2$)	160 ($users/km^2$)	6500 ($users/km^2$)	- ($users/km^2$)	- ($users/km^2$)	- ($users/km^2$)
Average Downlink Throughput	T	50 (Mbps/user)					100 (Mbps/user)		50 (Mbps/user)		100 (Mbps/user)	10 (Mbps/user)		
Number of Inhabitants	NU	1,092,507	1,294,722	679,336	795,461	382,086	1,271,628	391,749	14,464	9093	73,295	1111	~3500	~5000
Active Users Ratio	α	0.5					0.8		0.75		0.8	0.3		0.4
Probability of Usage	β	0.3					0.6		04		0.6	0.1		0.2
Electricity Grid Cost	CE	R 2.89 (/kWh)									No legal connection	No connection	No connection	No connection

Table A2. *Cont.*

Parameter		Symbol	Scenario												
			Mopani	**Vhembe**	**Waterberg**	**Chris Hani**	**Frances Baard**	**Soweto**	**Khayelitsha**	**Lulekani**	**Zeerust**	**Duduza**	**Hlankomo**	**Mandileni**	**Gon'on'o**
Solar Panel Power	UAV-Based	PSP	4.5 (kWp/site)	3.5 (kWp/site)	4.1 (kWp/site)	3.8 (kWp/site)	3.1 (kWp/site)	4.8 (kWp/site)	4.6 (kWp/site)	2.6 (kWp/site)	3.2 (kWp/site)	3.4 (kWp/site)	1.8 (kWp/site)	1.9 (kWp/site)	2.1 (kWp/site)
	LC-Based		12.7 (kWp/site)	12.6 (kWp/site)	11.5 (kWp/site)	10.7 (kWp/site)	12 (kWp/site)	12.8 (kWp/site)	12.5 (kWp/site)	10.7 (kWp/site)	10.8 (kWp/site)	10.2 (kWp/site)	10.2 (kWp/site)	10.5 (kWp/site)	10.2 (kWp/site)
	Hotspot-Based		7.5 (kWp/site)	7.6 (kWp/site)	7.5 (kWp/site)	7.5 (kWp/site)	6.9 (kWp/site)	9 (kWp/site)	8.1 (kWp/site)	6.5 (kWp/site)	6.3 (kWp/site)	6.8 (kWp/site)	6.4 (kWp/site)	6.5 (kWp/site)	6.9 (kWp/site)
Number of Batteries	UAV-Based	NB	15 (units/site)	13 (units/site)	12 (units/site)	20 (units/site)	15 (units/site)		6 (units/site)	5 (units/site)		5 (units/site)	3 (units/site)	10 (units/site)	7 (units/site)
	LC-Based		26 (units/site)	27 (units/site)	18 (units/site)	32 (units/site)	24 (units/site)	5 (units/site)	13 (units/site)	10 (units/site)	2 (units/site)	10 (units/site)	7 (units/site)	17 (units/site)	11 (units/site)
	Hotspot-Based		18 (units/site)	18 (units/site)	18 (units/site)	18 (units/site)	18 (units/site)	20 (units/site)	20 (units/site)	15 (units/site)	15 (units/site)	9 (units/site)	7 (units/site)	7 (units/site)	7 (units/site)
Number of Deployed 5G – Nodes	UAV-Based	NC – Max	30,809	39,408	69,149	56,053	19,763	23,654	7287	127	88	1364	3	3	5
	LC-Based		2117	2509	1317	1542	741	7885	2429	43	29	455	1	1	2
	Hotspot-Based		30,809	39,408	69,149	56,053	19,763	1514	467	11	88	88	1	1	1
	UAV-Based	NC – User	6351	7527	3949	4624	2222	23,654	7287	127	85	1364	3	3	5
	LC-Based		2117	2509	1317	1542	741	7885	2429	43	29	455	1	1	2
	Hotspot-Based		407	482	253	296	143	1514	467	9	6	88	1	1	1
	UAV-Based	NC – Area	30,809	39,408	69,149	56,053	19,763	308	60	11	88	18			
	LC-Based		78	99	173	141	50	1	1	1	1	1			
	Hotspot-Based		30,809	39,408	69,149	56,053	19,763	308	60	11	88	18			
Site Acquisition Costs	UAV-Based	CSA	ZAR 577.3 (k/site)					ZAR 173.3 (k/site)		ZAR 120 (k/site)			ZAR 120 (k/site)		
	LC-Based		ZAR 1732 (k/site)					ZAR 519.6 (k/site)		ZAR 480.8 (k/site)			ZAR 480.8 (k/site)		
	Hotspot-Based		ZAR 812 (k/site)					ZAR 240 (k/site)		ZAR 160 (k/site)			ZAR 160 (k/site)		
Monthly Subscription Fee		F	ZAR 400							ZAR 300			ZAR 20		

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