RES4AFRICA FOUNDATION

In knowledge partnership with enel Foundation

ACCESS TO ELECTRICITY IN URBAN AND PERI-URBAN AREAS IN SUB-SAHARAN AFRICA

POPULATION GROWTH AND ELECTRICITY ACCESS: CHALLENGES, INNOVATIVE SOLUTIONS, AND OUTLOOK

MICRO ENERGY INTERNATIONAL

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Foreword

Access to reliable and affordable energy remains a critical challenge in Sub-Saharan Africa. Despite recent progress in electrification, population growth has outpaced energy access, leaving the number of people without electricity consistently above 500 million between 2000 and 2024. This figure underscores a persistent gap in achieving the targets set under Sustainable Development Goal 7 (SDG7).

In many African countries, large segments of the population live in rural areas where energy infrastructure is scarce. Expanding energy access to these communities not only improves access to clean water and sanitation but also stimulates rural development through agricultural mechanization, value-added processing, and the growth of local industries. Enhanced energy access supports economic activities, reduces rural-urban disparities, and promotes inclusive development. Furthermore, reliable energy for shared services contributes to community security, safety, and social cohesion. As such, rural electrification remains a critical priority for sustainable development.

However, it is equally important to address the growing energy needs of urban and peri-urban areas. Rapid urbanization has led to the expansion of informal settlements where basic services, including electricity, water, and sanitation, are often lacking. Ensuring energy access in these areas is becoming as crucial if not more so as it is in rural regions, given the scale of urban migration and the concentration of economic activities.

In response to these challenges, RES4Africa has undertaken this study to examine energy access in urban and peri-urban areas of Sub-Saharan Africa, with the aim of identifying best practices and innovative solutions that can accelerate universal electrification. Ten megacities were selected to represent typical Sub-Saharan cases. Main challenges on electrification and possible solutions were identified. Lastly, for three megacities specific topics were chosen as potential pilot projects to be implemented in the near future.

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List of Abbreviations

AfDB	African Development Bank
AMI	Advance Metering Infrastructure
AS	Accelerated Growth Scenario
AU	African Union
BESS	Battery Energy Storage Systems
BGFA	Beyond the Grid Fund for Africa
BS	Baseline Constant Scenario
CAGR	Compound Annual Growth Rate
CBOs	Community-based organizations
DRC	Democratic Republic of Congo
DSM	Distributed Energy Resources
DSOs	Distribution System Operators
EaaS	Energy-as-a-Service
EAC	East African Community
ECOWAS	Economic Community of West African States
EWURA	Energy and Water Utilities Regulatory Authority
GERD	Grand Ethiopian Renaissance Dam
IDA	International Development Association
LCDAs	Local Council Development Areas
LCOE	Levelized cost of electricity
LSEB	Lagos State Electricity Board
LSMS	Living Standards Measurement Study
MoE	Ministry of Energy
MTF	Multi-Tier Framework
NBS	National Bureau of Statistics
NEP	National Energy Policy
PHC	Population and Housing Census
PPPs	Public-private partnerships
PRSP	Poverty Reduction Strategy Paper
PUE	Productive Use of Energy
PV	Photovoltaic
RBF	Results-Based Financing
REA	Rural Electrification Authority
REMP	Rural Electrification Master Plan
RETs	Renewable Energy Technologies
SADC	Southern African Development Community
SDGs	Sustainable Development Goals
SHS	Solar Home Systems
SSA	Sub Saharan African
UPBEAT	Utility Performance and Behavior in Africa Today
UN	United Nations
V2G	Vehicle-to-Grid
VPPs	Virtual Power Plants

Executive summary

Access to reliable electricity is a cornerstone of economic development, social progress, and the achievement of Sustainable Development Goal (SDG) 7 ensuring universal, affordable, and sustainable energy by 2030. However, Sub-Saharan Africa (SSA) remains the least electrified region globally, with 600 million people lacking access, 590 million of whom are in SSA. Rapid urbanization, population growth, and underdeveloped infrastructure have created a persistent energy gap, particularly in urban and peri-urban areas, where informal settlements and unreliable grids leave millions without stable power.

This report analyzes 10 selected SSA cities, projecting their population and electricity access trends to 2030 and 2050, identifying key challenges, and proposing scalable solutions to achieve 100% electrification.

Key Findings

Urbanization and Population Growth

- SSA's urban population is projected to be more than double by 2050, with megacities cities like Kinshasa (DRC) and Lagos (Nigeria) leading growth
    - Lagos: Expected to grow from 16.5 million (2024) to 38 million by 2050 (Baseline Constant Scenario)
    - Kinshasa: From 17 million (2024) to 48 million by 2050(Baseline Constant Scenario), potentially the largest city in Africa by 2050
- Secondary cities (Dar es Salaam, Lusaka, Nairobi) are among the fastest growing cities, driven by rural-urban migration and economic opportunities

Electricity Access Gaps

- While Urban electrification averages 78%, but 110 million urban dwellers remain unconnected, often living "under the grid" due to:
    - High connection costs (e.g., $240 to $400 in Lusaka)
    - Unreliable supply (frequent blackouts in Nigeria, DRC)
- Under current growth trends, only 4 of 10 selected cities (Lagos, Kigali, Dar es Salaam, Lusaka) can achieve a theoretical 100% electrification by 2030–2050
- Accelerated investment could bridge these gaps but requires $28 billion/year until 2030

Critical Challenges

- Supply-side barriers: Aging infrastructure, funding gaps ($28 billion/year needed), and power theft and high losses (e.g., Nigeria's 14% theft rate)
- Demand-side barriers: High connection costs, low willingness-to-pay, informal settlement (complicated grid expansion) and unreliable supply
- Policy and regulatory barriers: Weak regulatory frameworks and bureaucratic inefficiencies hinder private investment

Proposed Solutions

- Grid Modernization and expansion of decentralized energy
    - Smart grids and advanced metering (AMI) to reduce losses and theft, improve billing accuracy (e.g., Lagos, Johannesburg)
    - Decentralized models: Solar hybrids mini/micro-grids for informal settlements (e.g., Nairobi's slums)

- **Innovative Financing**
    - Pay-as-you-go (PAYG) (e.g., ENGIE Energy Access in Nairobi and ZOLA Electric in Dar es Salaam)
    - Community solar programs to improve affordability.
    - Public-private partnerships (PPPs) for infrastructure upgrades (e.g., Zambia's REA incentives)

- **Policy Reforms**
    - Streamlined regulations to attract private capital (e.g., Nigeria's 2023 Electricity Act)
    - Integrated urban-energy planning (e.g., Kigali's Master Plan 2050)

Recommendations for Feasibility Studies

- **Lagos**
    - Solar mini/micro-grids for residential zones that have developed outside formal urban planning and regulatory frameworks (e.g., Makoko, Ajegunle)
    - Advanced Metering Infrastructure (AMI) to reduce theft and improve billing accuracy

- **Nairobi**
    - Delegated management models for slum electrification.
    - Mobile battery-swapping stations for flexible power in informal settlement areas

- **Johannesburg**
    - Solar mini/micro-grids to reduce reliance on Eskom's instable grid
    - Advanced Metering Infrastructure (AMI) rollout to improve billing and reduce non-technical losses

In essence, achieving universal electricity access in SSA's urban and peri-urban areas demands urgent investment, innovative technologies, and inclusive policies. By prioritizing grid resilience, decentralized solutions, and stakeholder collaboration, cities can unlock sustainable development and economic potential. Immediate action is critical to meet SDG 7 by 2030 and support Africa's urban future.

1.0 Introduction

1.1. Background

Access to electricity is essential for driving economic growth and supporting vital social services, including health and education, in both developed and developing countries. The Sustainable Development Goals (SDGs) emphasize this importance, aiming to ensure universal access to affordable, reliable, and sustainable clean energy by 2030. Similarly, the African Union Commission envisions that by 2063, all businesses, industries, institutions, and households in Africa will have access to modern, efficient, cost-effective, and reliable energy[1].These objectives highlight the critical role of electricity access in a nation's economic development and success.

Sub Saharan African (SSA) cities are projected to experience some of the fastest population growth rates globally through 2035, with urbanization advancing rapidly in the region's largest cities, and urban clusters(concentrated settlements within or on the outskirts of cities that often exhibit high population density and varying levels of access to services and infrastructure) By 2035, the top 100 cities in Africa referred to as Africa100, encompassing cities with populations exceeding 1 million as well as smaller capitals are expected to house around 21% of the continent's population while generating over 60% of its GDP[2]. Established urban centres and megacities like Cairo, Lagos, and Johannesburg will continue to lead Africa100 city economies. However, middleweight cities such as Kinshasa, Dar es Salaam, Addis Ababa, Abidjan, Kampala, Dakar, and Kumasi are anticipated to grow at a much faster rate, fuelled by infrastructure development, increasing urbanization, and the rise of new megacities[2].

In SSA cities, urbanization is often influenced by a combination of rural "push" factors and urban "pull" factors[3]. Rural push factors compel people to leave their villages and towns due to poor living conditions, widespread poverty, political neglect, environmental degradation, inadequate healthcare and educational facilities, and a lack of essential infrastructure. In contrast, urban pull factors attract migrants to cities, offering better job opportunities, improved living standards, modern infrastructure, and access to superior education and healthcare services[3].

Rapid urbanization in Sub-Saharan Africa is driving market growth, connectivity, and trade, but also creating challenges like overcrowding, informal settlements, unemployment, and energy poverty. With urban populations projected to exceed 68% by 2050[4]. This expansion is intensifying electricity demand in urban and peri-urban areas, while infrastructure development struggles to keep pace. Decentralized energy systems, mini-grids, and renewables are emerging as scalable solutions to bridge the gap. This study analyzes electrification trends, challenges, and opportunities for 2030 and 2050, aiming to support universal energy access aligned with SDG 7.

2.0 Urban Population in Sub-Saharan Africa Today

2.1 Current Population Trends

Sub-Saharan Africa refers to the region of the African continent located south of the Sahara Desert, encompassing 48 countries, including 23 low-income, 18 lower-middle-income, six upper-middle-income, and one high-income nation (Seychelles). Excluding North Africa, this region spans Southern, West, Central, and East Africa, with most of its land lying in tropical climates between the Tropic of Cancer and Tropic of Capricorn, where average temperatures hover around 18°C year-round, except in cooler uplands and the temperate southern tip. Seven of the eight regional economic organizations recognized by the African Union (AU) include sub-Saharan members, such as ECOWAS, SADC, and EAC, with overlapping memberships being common among countries[5].

According to the Integrated Future Scenarios (IFs) 7.63 Tableau Public workbook, which incorporates data from the United Nations Population Division's Population Prospects, Sub-Saharan Africa's population stood at 1.106 billion in 2019, reflecting a 117.77% increase since 1990. Projections indicate that this growth will continue, with the population expected to rise by 77.38% to reach 1.962 billion by 2043 under the Current Path forecast[6].

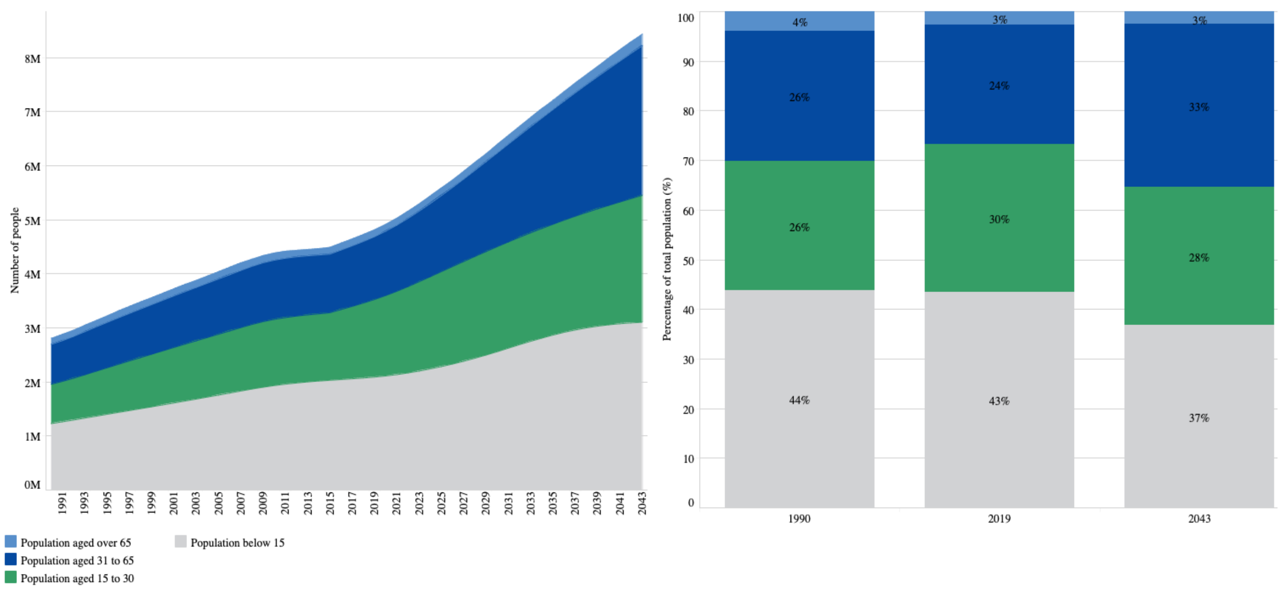


Figure 1: Population trends in Sub-Saharan Africa by age group from 1990 to 2043(Source:[6])

As observed on the **Figure 1**, the region is characterized by a young demographic, with 43% of the population under the age of 15 and 28% under 30. The median age, which was 18.74 in 2019, is projected to increase to 22.82 by 2043, driven by declining fertility rates and improvements in healthcare. Economic growth in SSA rose from 2.4% in 2023 to 3% in 2024, with projections indicating a further rise to 4% by 2025-2026. However, this growth is uneven, with East and West Africa projected to see modest gains, and larger economies like South Africa and Nigeria facing persistent energy, transportation, and sectoral challenges. Rising conflict, military takeovers, and climate-related shocks further hinder regional development, leaving 464 million people in extreme poverty and 53% of developing countries eligible for concessional support from the International Development Association(IDA) at high risk of debt distress[7].

According to IFs 7.63(**see Figure 2**), a Tableau Public workbook using data from the UN Population Division's Population Prospects, Sub-Saharan Africa was predominantly rural in 2019, with over half the population in 31 of its 48 countries residing in rural areas and an average urbanization rate of just 40.4%. By 2043, urbanization is expected to surpass the rural population, with 50.5% of people living in urban areas[8].

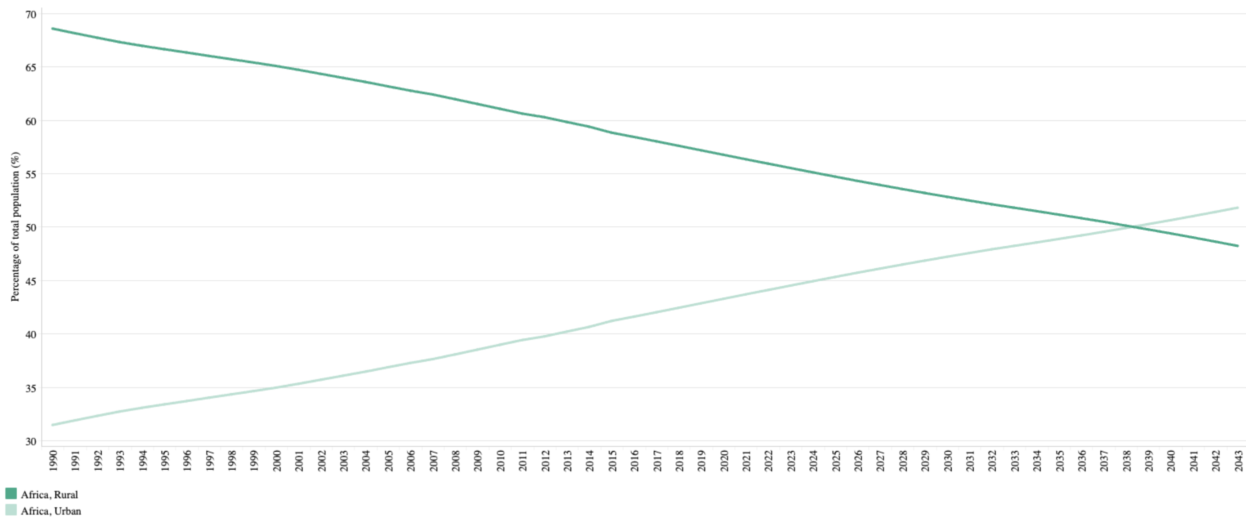


Figure 2: Urban and rural population trends in Sub-Saharan Africa, 1990–2043 (Source: [8])

Sub-Saharan Africa is undergoing rapid population expansion, with the most substantial increases concentrated in urban and peri-urban areas. This urbanization trend presents both opportunities and challenges in terms of infrastructure, service delivery, and sustainable development. To gain deeper insights into these demographic dynamics, a group of 27 cities together with their peri-urban surroundings has been identified for preliminary analysis. As shown in **Figure 3**, population estimates for 2024 highlight cities like Lagos in Nigeria, and Kinshasa in the Democratic Republic of Congo as leading examples of this growth, each exceeding 7 million inhabitants. In addition, cities such as Lusaka, Zambia, and emerging urban centres in Tanzania are witnessing steady expansion, reflecting broader regional patterns of urbanization across the region[9].

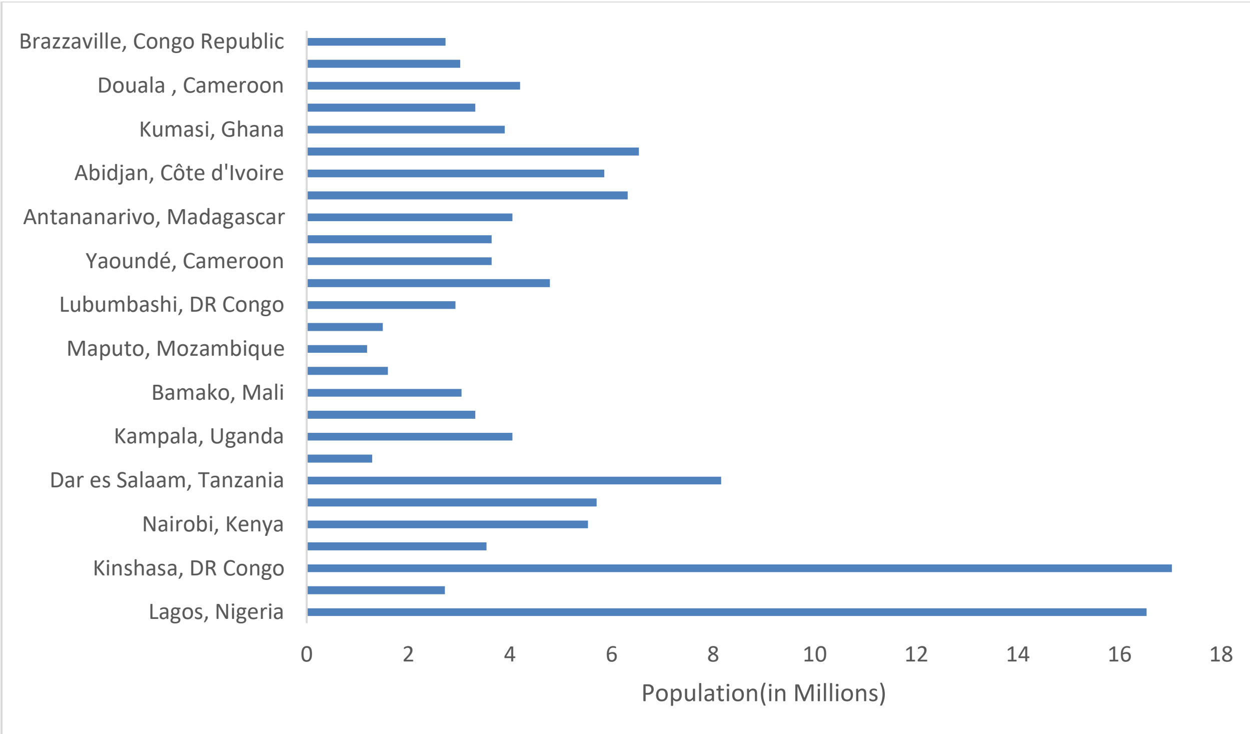


Figure 3:Estimated Population of Selected Cities in Sub-Saharan Africa as of 2024(Source: Adapted from[9])

The initial group of 27 cities represents a wide spectrum of population sizes, growth trajectories, and geographic locations across SSA. From this group, a final list of 10 cities will be selected for detailed analysis based on specific criteria, including current population growth, electrification rates, and future development projections.

Methodology for selecting 10 Cities

The selection process was designed to ensure a representative and balanced sample of urban and peri-urban areas, reflecting the region's demographic and energy access diversity. The methodology comprised four key steps: initial shortlisting, development of a selection matrix, scoring and ranking, and final selection. Cities were evaluated based on factors such as population dynamics, electrification levels, and geographic representation (**see Table 1**), ensuring that the final selection aligns with the study's goals and provides insights applicable across varying contexts in SSA.

Table 1: Cities selection criteria (Source: MicroEnergy international)

Criteria	Description and rationale	Scoring
City Size	Major metropolitan areas with large populations were prioritized as they are likely to face greater electrification demands and economic challenges. Cities were scored from 3 (smaller cities) to 5 (largest cities)	Green – 5 points (good), Yellow – 4 points (average), Red – 3 points (poor) Grey - total score
Growth Rate	Cities with rapid urbanization rates, high population growth, and infrastructure development were given higher scores. Rapid growth generally correlates with increasing energy demand, making these cities critical areas for electrification efforts. Scores ranged from 3 (slow growth) to 5 (high growth)	
Geographic Location	To ensure geographic diversity, cities were pre-selected from various regions of SSA, including West, East, Central, Southern, and the Horn of Africa. Cities in underrepresented regions (e.g. East, central, southern Africa) from the preselection received higher scores to balance regional representation. Scores ranged from 3 (overrepresented regions) to 5 (underrepresented or strategically important regions)	
Economic and Industrial Importance	Cities with significant economic and industrial roles scored higher. These cities often serve as economic hubs, models for energy access, or key locations for industry-driven electrification. Scores ranged from 3 (low economic influence) to 5 (major economic centres)	
Electrification Needs	Cities with substantial electrification gaps, especially in peri-urban areas, were given higher scores, as these are areas where infrastructure is either in development or urgently needed. Scores ranged from 3 (low electrification need) to 5 (high electrification need)	
Political Stability	Stable political environments are essential for sustainable electrification efforts. Cities in politically stable countries scored higher, as these locations are more conducive to long-term investment and project implementation. Scores ranged from 3 (unstable) to 5 (stable)	
Regulatory Framework for Electrification	Cities in countries with strong, supportive regulatory frameworks for electrification scored higher. These frameworks are crucial for successful project deployment and the sustainable expansion of energy access. Scores ranged from 3 (weak or evolving frameworks) to 5 (robust frameworks)	
Ratio of Formal vs. Informal Urbanization (Spontaneous Growth)	Cities with high levels of informal, spontaneous growth (unplanned urban expansion lacking formal infrastructure), received higher scores, as these areas often lack organized infrastructure, presenting significant electrification challenges. Scores ranged from 3 (low informal urbanization) to 5 (high informal urbanization)	

Cities were evaluated using a scoring system ranging from 3 to 5 points, based on expert analysis and desk research. High-performing cities scored green (5), average cities yellow (4), and low-performing cities red (3). Scores were summed across all criteria, resulting in a ranked list that highlighted cities with the greatest need and potential for targeted electrification interventions. This ranking enabled strategic prioritization (**see Table 2**).

Table 2:Selection Matrix Scoring and Ranking (Source: MicroEnergy International-2025)

No.	City	City Size	Growth Rate	Geographic Location	Economic & Industrial Importance	Electrification Needs	Political Stability	Regulatory Framework	Formal vs. Informal Urbanization	Total Score	Sources
1	Lagos, Nigeria	5	5	4	5	5	4	4	4	36	[10],[11],[12],[13]
2	Accra, Ghana	4	4	4	4	4	5	5	3	33	[14],[15],[16]
3	Kinshasa, DR Congo	5	5	4	4	5	3	4	5	35	[17],[18],[19],[20]
4	Darka, Senegal	4	3	5	3	4	5	4	3	31	[21]
5	Nairobi, Kenya	5	4	5	5	4	5	5	3	36	[22],[23]
6	Addis Ababa, Ethiopia	5	5	5	4	4	4	4	4	35	[24],[25]
7	Dar es Salaam, Tanzania	4	5	5	4	4	5	5	3	35	[26],[27][28]
8	Kigali, Rwanda	3	4	5	4	4	5	5	3	35	[29],
9	Kampala, Uganda	4	4	5	4	4	4	4	4	33	[30],[31]
10	Luanda, Angola	4	3	5	4	5	5	4	4	34	
11	Bamako, Mali	3	4	5	3	5	3	4	4	31	[32]
12	Harare, Zimbabwe	4	3	4	3	5	3	3	3	27	
13	Maputo, Mozambique	4	4	5	5	5	4	4	4	35	[33]

14	Mombasa, Kenya	3	3	5	4	4	5	4	3	31	[34]
15	Lubumbashi, DR Congo	4	4	4	4	4	3	3	4	30	[17]
16	Juba, South Sudan	3	4	5	3	5	3	3	4	30	[35]
17	Yaoundé, Cameroon	4	3	4	3	5	4	4	4	29	[36]
18	Port Harcourt, Nigeria	4	4	4	5	5	3	3	4	32	[11]
19	Antananarivo, Madagascar	4	3	5	3	5	3	3	4	30	[37]
20	Johannesburg, South Africa	5	4	5	5	3	5	5	5	37	[38]
21	Abidjan, Côte d'Ivoire	5	4	4	5	4	5	5	5	37	[39]
22	Khartoum, Sudan	4	4	5	4	4	3	3	4	31	[35]
23	Kumasi, Ghana	4	4	4	4	4	5	5	4	34	[21]
24	Lusaka, Zambia	4	4	5	5	5	4	5	4	36	[40]
25	Douala, Cameroon	4	4	5	5	4	4	3	4	33	[36]
26	Mbuji-Mayi, DRC	3	3	4	3	4	3	3	4	27	[17]
27	Brazzaville, Republic of the Congo	3	3	4	3	4	3	3	4	27	

The selection of the 10 cities was guided by a methodology designed to ensure regional diversity across West, East, Central, and Southern Africa, resulting in a geographically balanced representation of Sub-Saharan Africa. Cities were chosen based on high cumulative scores against predefined criteria, including population growth, urbanization trends, and electrification needs. This process prioritized locations that illustrate both pressing energy access challenges and potential for impactful interventions. Collectively, the selected cities form a diverse and strategically relevant sample that aligned with the study's objective of addressing energy access in rapidly growing urban and peri-urban areas.

Table 3: Selected Cities and characteristics (Source: MicroEnergy International-2025)

City	Score	Characteristics of selected cities
Johannesburg, South Africa	37	Although Johannesburg has relatively lower electrification needs due to existing infrastructure, it scored highly in terms of economic importance, political stability, and regulatory support. This makes it an ideal city for sustainable electrification models.
Abidjan, Côte d'Ivoire	37	A major economic hub with diverse industrial activities. Its growth rate, regulatory strength, and urbanization balance make it a suitable representative for West Africa.
Nairobi, Kenya	36	Nairobi was selected due to its significant economic role, growth rate, and established electrification policies. As a central economic hub in East Africa, Nairobi has both the demand for energy and a regulatory framework supportive of electrification efforts.
Lagos, Nigeria	36	Lagos scored high across nearly all criteria due to its massive population, rapid urbanization, significant electrification needs, and informal urbanization challenges. It serves as a major economic hub and faces immense pressure for energy access.
Lusaka, Zambia	36	Lusaka ranked high due to its rapid urbanization, population growth, and substantial electrification gaps. As Zambia's capital, it is a major urban centre with increasing economic activities and rising energy demands. Lusaka's regulatory environment and government focus on energy access create an ideal opportunity for implementing sustainable electrification models.
Addis Ababa, Ethiopia	35	Addis Ababa scored high for growth rate, electrification needs, and regulatory framework. The Ethiopian government is prioritizing electrification, and rapid urbanization is increasing the demand for reliable energy access.
Maputo, Mozambique	35	Maputo scored well in terms of electrification needs and urbanization challenges. As the capital and economic hub of Mozambique, it has a rapidly growing population and significant demand for modern energy access. The city also benefits from ongoing government initiatives aimed at expanding energy infrastructure, making it a valuable representative for electrification efforts in Southern Africa.
Dar es Salaam, Tanzania	35	Dar es Salaam scored well in terms of size, growth rate, and electrification needs. It is a major urban centre with expanding energy infrastructure needs, especially in peri-urban areas.

Kigali, Rwanda	35	Kigali scored high on stability, regulatory support, and growing electrification needs. Its small but rapidly urbanizing population and government support for energy initiatives make it an important case for electrification studies.
Kinshasa, DRC	35	Kinshasa scored high in city size, growth rate, electrification needs, and informal urbanization. As one of Africa's fastest-growing cities, Kinshasa's energy infrastructure is severely underdeveloped, making it a prime candidate for electrification projects. However, its highly politically unstable.

Figure 4 illustrates the population trends of the ten selected cities from 2000 to 2024, offering a comprehensive view of urban growth over the past 24 years. The data reveals diverse rates of population change, shedding light on key drivers of urbanization, including economic opportunities, migration patterns, infrastructure expansion, and political conditions.

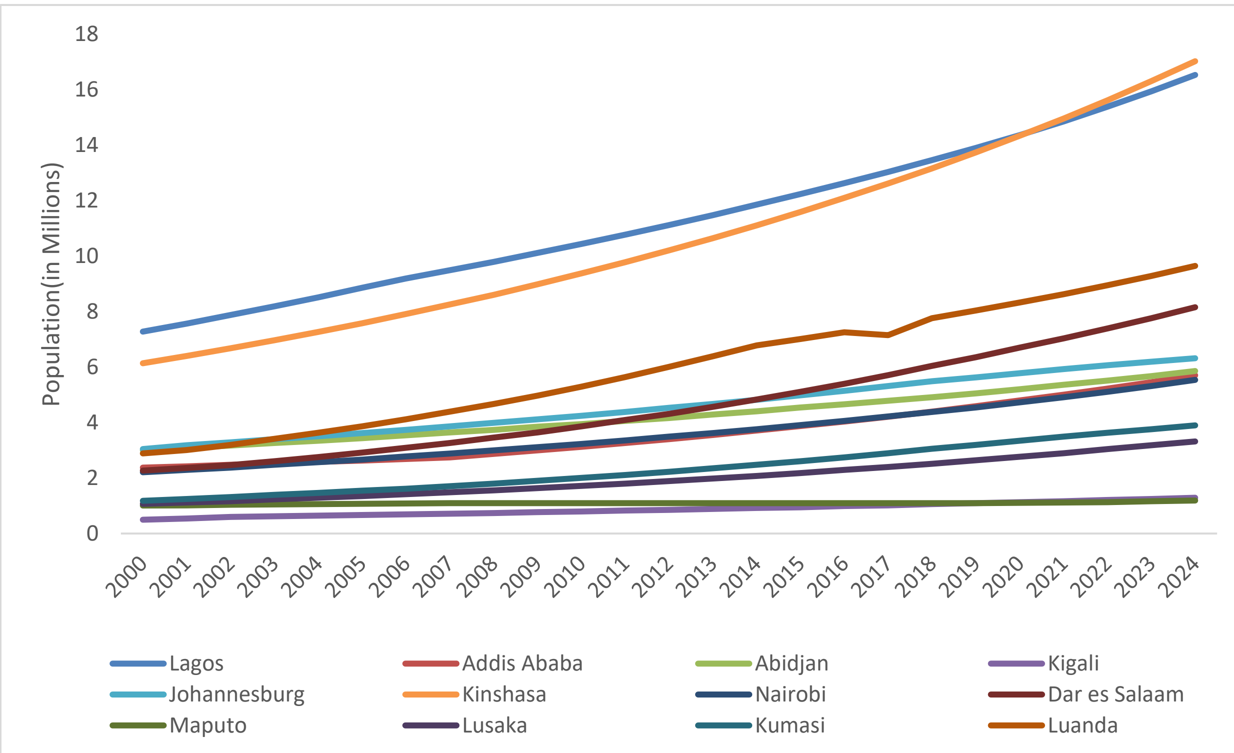


Figure 4: Population Growth Trends in Selected Cities for the Period 2000–2024(Source: Adapted from [9])

Figure 4 illustrates significant urban population growth across major African cities between 2000 and 2024. Lagos, Nigeria, shows a remarkable increase from 7.28 million to 16.54 million, underscoring rapid urbanization and its role as a key economic centre. Kinshasa, DR Congo, records the most dramatic growth from 6.14 million to 17.03 million making it the fastest-growing city among those analysed and highlighting its rising prominence in Central Africa. Cities like Nairobi and Dar es Salaam have also seen their populations more than double, driven by expanding economic opportunities and ongoing rural-to-urban migration.

Mid-sized cities such as Addis Ababa, Abidjan, and Kigali demonstrate steady demographic expansion, reflecting their growing importance as regional administrative and economic hubs. Addis

Ababa's population rises from 2.38 million to 5.70 million, while Kigali experiences a nearly threefold increase from 0.498 million to 1.29 million indicative of successful post-conflict recovery and development. Abidjan's growth from 3.01 million to 5.86 million signals its revitalization as a commercial gateway in West Africa.

Smaller cities, including Kumasi, Johannesburg, and Luanda, also exhibit consistent growth. Kumasi expands from 1.18 million to 3.90 million, reinforcing its status as Ghana's cultural and economic hub. Johannesburg, increasing from 3.05 million to 6.32 million, shows more gradual growth, likely due to its already mature infrastructure. Luanda, meanwhile, grows significantly from 2.89 million to 9.65 million, reflecting substantial urban expansion following Angola's post-war recovery.

2.2 Urbanization Patterns

Urban areas and urbanization are described and interpreted in various ways, often using factors such as demographic shifts, employment sectors, infrastructure development, and physical boundaries. An urban area, for the purposes of this study, refers to a geographic area with a minimum population concentration of 1,000 people and a population density of at least 400 persons per square kilometre, based on the latest census data. While a peri-urban area is characterized as the transitional zone located at the interface between urban and rural environments. These areas often exhibit a mix of urban and rural characteristics, including rapid land-use changes, lower population densities compared to urban areas, and significant socio-economic interaction with the urban centres they surround[41]. From a demographic viewpoint, urbanization is seen as the growing share of a country's population residing in urban centres, largely driven by migration from rural to urban areas rather than natural population growth. Urbanization also includes the spatial expansion of urban areas, often marked by a transition from compact settlements to more spread-out ones.

Urbanization is accelerating worldwide, with the global urban population projected to rise from 47% in 2000 to 57% by 2050. Over 90% of this growth will occur in developing countries, with Africa experiencing the highest urbanization rate at 3.5% annually, a trend expected to continue through 2050. Despite this rapid growth, urbanization in Africa has not led to inclusive development, resulting in widespread slums, poverty, and rising inequality. African cities have the second-highest inequality globally, with an average Gini coefficient **of 0.58**, indicating a high level of income inequality. (The Gini coefficient ranges from 0 to 1, where 0 represents perfect equality and 1 represents maximum inequality). Rural-to-urban migration and natural population growth are the main drivers of urban expansion and slum proliferation on the continent[42].

Over the past decade, urbanization in Sub-Saharan Africa has experienced consistent growth, reflecting a steady shift in population dynamics across the region (**See Figure 5**).

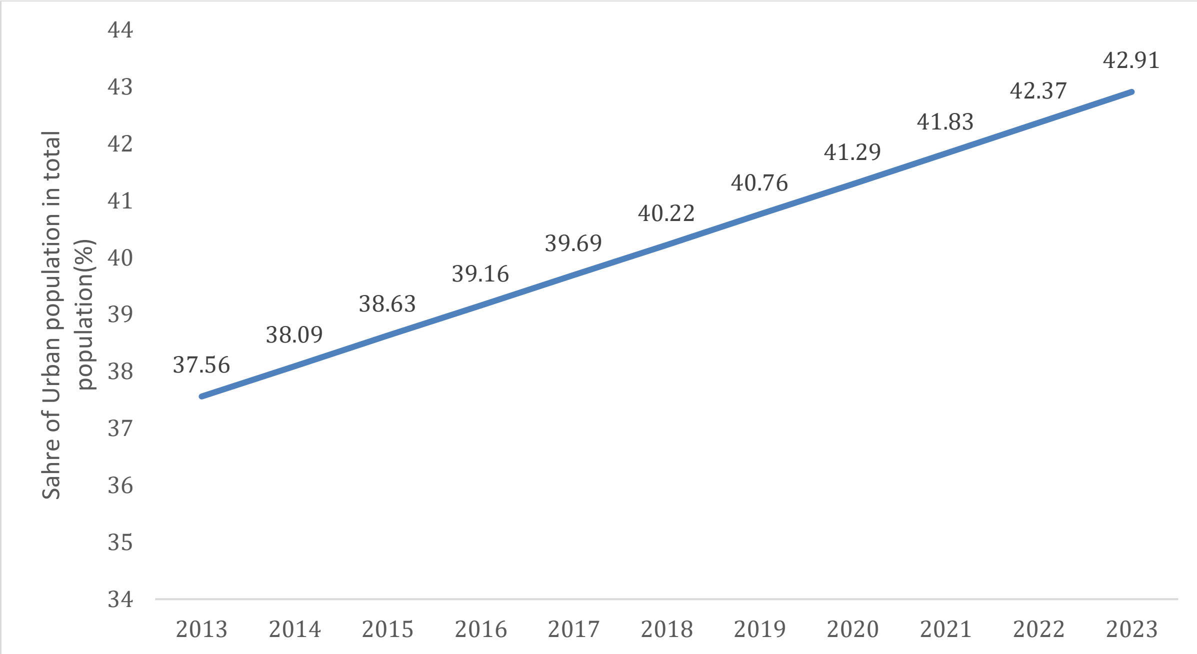


Figure 5: Urbanisation in Sub-Saharan Africa from 2013 to 2023(Source: Adapted from [42])

Urbanization in Sub-Saharan Africa has increased from 37.56% in 2013 to 42.37% in 2022, marking a growth of nearly 5 % points over a decade. This corresponds to an average annual increase of approximately 0.5 percentage points. The trend reflects the steady migration from rural to urban areas, driven by the search for economic opportunities, improved access to services, and enhanced infrastructure in cities.

Urbanization patterns for the 10 selected cities

SSA's position as home to some of the world's fastest-growing cities underscores its pivotal role in shaping future urbanization trends. This growth significantly impacts electricity demand, as urban and peri-urban areas require expanded energy infrastructure to support residential, commercial, and industrial activities. The rising need for reliable power intensifies the urgency to scale up sustainable and efficient energy solutions, especially in contexts where existing grids are often inadequate. Specific considerations related to the 10 selected cities are below indicated.

Kinshasa

Occupying an area of 9,965 square kilometres, Kinshasa lies along the southern shores of the Pool Malebo on the Congo River[43]. Kinshasa serves as one of the 26 provinces of the Democratic Republic of the Congo and is administratively divided into 24 communes, further subdivided into 365 neighbourhoods. Although it has a vast administrative region, urban areas still cover only 4% of the total land area while most of its land remains rural, with urban development concentrated mainly on its western side[20].

The Democratic Republic of Congo is experiencing rapid population growth, with projections indicating an increase from 133 million in 2030 to 191 million in 2040 and eventually reaching 278 million by 2050. Within this context, the city of Kinshasa has emerged as a focal point of urban expansion, with its population increasing sevenfold between 2005 and 2009 and continuing to grow at over 4% annually since 2010. Factors such as war have driven rural-urban migration, further intensifying housing demand and accelerating urban sprawl (**See Figure 6**). Despite this growth, urban areas still cover only 4% of the total land area, concentrated primarily in a few municipalities[20].

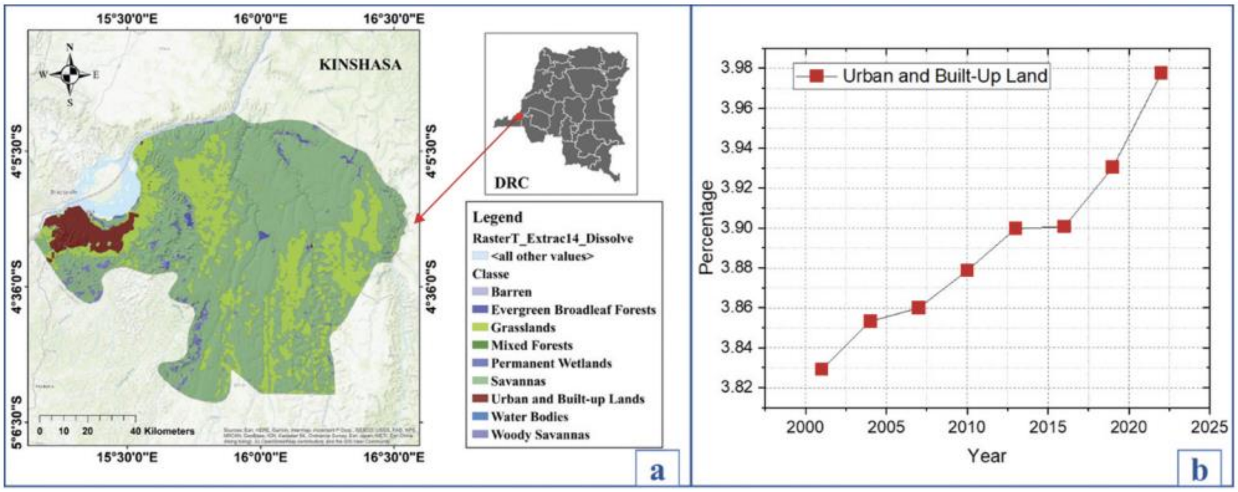


Figure 6: Land use and cover map of the city of Kinshasa in 2022. b) evolutionary curve of the urban and built-up land class from 2001 to 2022 with intervals of 3 years (Source: [20])

This expansion has been uneven and unregulated. Unregulated urbanization in Kinshasa has led to several critical issues, including the proliferation of slums, infrastructure collapse during torrential rains, and severe flooding caused by improper housing in riverbeds. For instance, flooding between December 2023 and January 2024 inundated numerous households in the Ngaliema municipality due to the Congo River's overflow. Blocked drainage systems and inadequate waste management further exacerbate these problems, while traffic congestion persists due to poor infrastructure, outdated city planning from the colonial era, and lack of effective road regulation. These challenges highlight the urgent need for sustainable urban planning and disaster mitigation measures[20].

Lagos, Nigeria

In Nigeria urbanization is largely driven by economic growth stemming from industrialization and leading to the migration of people from rural areas to urban centres. Lagos physical layout and socio-economic structure have played a pivotal role in its urban growth and expansion. Rural-urban migration has been significantly influenced by the promise of better employment opportunities in Lagos, underscoring the influence urban centres exert on surrounding rural areas. The key factors driving urbanization and population growth in Lagos include employment prospects, industrialization, modernization, and various social incentives. Collectively, these elements have fuelled the city's rapid urban expansion, as illustrated in **Figure 7**.

The Lagos Metropolis comprises 16 urban local government areas within Lagos State, which encompasses a total of 20 local governments 16 urban and 4 rural. In addition, there are 37 Local Council Development Areas (LCDAs) within the state. The city extends beyond the state's boundaries to include peri-urban areas, towns, and villages within four additional local governments.

At the heart of the city is the historic Lagos Island, which includes Victoria Island and serves as a major hub for the central business district. While the state's administrative centre is now situated in Ikeja on the mainland. Informal settlements surround the central business district, with Makoko being the most prominent and housing around 300,000 residents. Other notable areas include commuter neighbourhoods such as Apapa, FESTAC, and Satellite Town, as well as newer residential zones along the Ibadan expressway and Lekki Peninsula. A significant portion of Lagos residents, over 60%, reside in informal settlements, highlighting the substantial urban challenges facing the city[44].

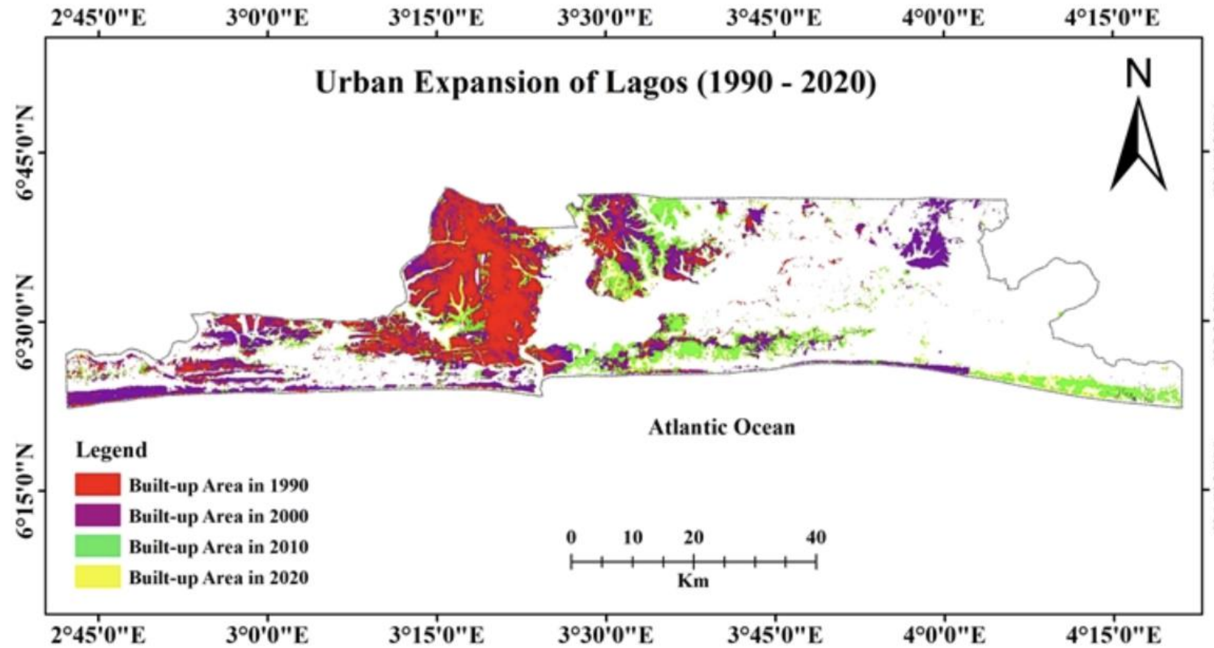


Figure 7:Lagos City's Urban Growth Map (Source: [44])

Slums and informal settlements in Lagos are characterized by low-income housing with poor living conditions, including deteriorated traditional slums with old, neglected structures. These areas are often partitioned and rented out to less privileged families, serving as housing for rural migrants who move to Lagos in search of better opportunities. The rapid growth of these settlements is attributed to the government's inability to provide adequate and affordable housing for the city's expanding urban population. Many of these settlements develop haphazardly in vulnerable areas prone to flooding, erosion, building collapse, and other environmental hazards, reflecting the challenges of managing a growing population without sufficient housing infrastructure[3].

The housing deficit in Lagos, estimated at over 5 million units or approximately 31% of Nigeria's national housing shortfall, significantly drives the expansion of slums and informal settlements[3]. Inadequate urban planning policies and strategies further exacerbate this issue, resulting in insufficient housing and essential infrastructure. Over the years, the number of slum districts in Lagos has risen dramatically, from 42 to over 200, ranging from small shacks under highways to extensive neighbourhoods[3]. A notable example is the Makoko floating settlement, as illustrated in **Figure 8.**

Figure 8:Makoko floating slum settlement in Lagos(Source: [3])

Dar es Salaam

The 2022 Population and Housing Census (PHC) results reveal significant population growth in Tanzania. The total population increased from 44.9 million in 2012 to 61.7 million in 2022, reflecting an annual growth rate of 3.2%. On the mainland, the population rose from 43.6 million in 2012 to 59.9 million in 2022[45]. Dar es Salaam City covers a total area of 1,393 square kilometres, representing approximately 0.15% of the total land area of Tanzania's mainland[46].

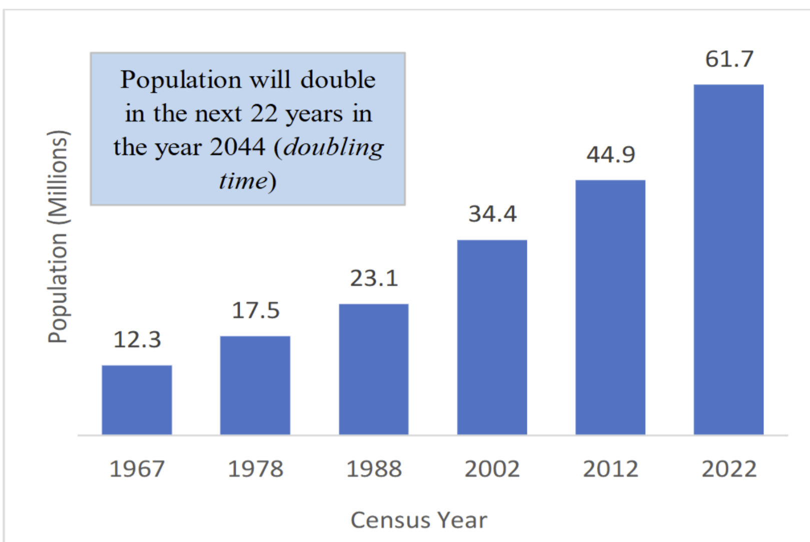


Figure 9:Trends in Population and housing from 1967 to 2022 in Tanzania Mainland (Source: [45])

The 2022 Population and Housing Census results reveal that Dar es Salaam is the most populous region in Tanzania, with a population of 5,383,728, representing 8.7% of the country's total population. Urban planning has been ineffective, with master plans from 1949, 1968, and 1979 having minimal impact. Rapid population growth since the 1980s has outpaced housing and infrastructure provision, resulting in widespread informal settlements, now home to 80% of the city's residents. Critical infrastructure, including electricity, has been poorly integrated into urban planning, with residents often left to arrange services independently[47].

A study done in 2022 by Constantine George in *The transformation of cities in Tanzania* revealed that lower-income individuals, less educated people, and women are more likely to migrate to Dar es

Salaam, primarily seeking better job opportunities and improved access to public services. Many migrants, particularly women, perceive urban areas as offering better public transport (70%), recreation (69%), market opportunities (68%), education (64%), and healthcare (64%)[28].

Resource constraints in low-income and peri-urban areas, such as Mbagala, Chamazi, and Mabwepande, leave communities underserved, with grid extensions struggling to keep pace with urban growth. While Dar es Salaam boasts an electricity access rate of 85.7%, far above the national average of 37.7%, affordability issues, frequent outages, and infrastructure disparities remain persistent challenges. Many residents rely on informal or shared grid connections, prioritizing basic needs like lighting and fans while avoiding high-energy appliances. In unplanned neighbourhoods, solar power, charcoal, and paraffin often serve as primary energy sources, with grid reliability issues prompting widespread adoption of solar, hybrid systems, and backup generators. As Tanzania's economic hub, consuming about a third of the nation's electricity, Dar es Salaam exemplifies the pressing need for sustainable energy solutions and improved infrastructure[47].

Addis Ababa, Ethiopia

Addis Ababa dominates Ethiopia's urban system, with a population nearly ten times larger than the second-largest city, Gondar. It serves as the country's administrative, diplomatic, and economic hub, connected to other urban centres by road and rail infrastructure, including links to Djibouti and Nairobi. The city's growth has spurred urbanization in eight surrounding satellite towns within the Oromia region.

Addis Ababa, the capital city of Ethiopia, expanded from a settlement of around 15,000 people in 1888 to over 3.6 million by 2020. According to Ethiopia's Central Statistical Agency, the population is projected to exceed 5 million by 2036. Despite this growth, the city's annual growth rate has slowed over the decades, declining from 6.9% in 1961–62 to 2% between 2007 and 2013. The federal system introduced in Ethiopia in 1991, and the subsequent decentralization of power and resources have encouraged migration to secondary cities, reducing Addis Ababa's growth rate. However, net migration remains significant, particularly as the population continues to grow despite a decline in fertility rates[48].

Over the years, Addis Ababa has experienced significant expansion in both its geographical size and population. From just 32 km^2 in 1912, the city's administrative boundaries have grown to 527 km^2 by 1994. Similarly, its built-up areas have expanded from 80.6 km^2 in 1984 to 364.5 km^2 by 2015. This rapid growth, driven by public housing projects and economic development, has led to urban sprawl and a decrease in population density from 182 to 96 persons per hectare. The inner city continues to struggle with deteriorating housing conditions, with approximately 70-80% classified as slums. To address this issue, the government initiated a housing program that has seen the construction of over 200,000 subsidized condominium flats since 2005. However, high initial payments and ongoing mortgage costs have made these units unaffordable for many residents, leading some beneficiaries to return to the slums. As a result, around 768,000 individuals are still on the waiting list for affordable housing in the city[48].

Nairobi, Kenya

Nairobi, the administrative and commercial hub of Kenya, covers an area of 684 km^2, making it the smallest province in Kenya. The city is strategically divided into divisions including Mathare, Westlands, Starehe, Dagoreti, Langata, Makadara, Kamkunji, and Embakasi. Nairobi displays prominent disparities in both income levels and population densities, with affluent residents predominantly residing in the western suburbs, while the eastern suburbs are primarily inhabited by lower- and middle-income groups[22].

Nairobi has grown rapidly from 11,000 residents in 1910 to over 1 million households today, which equates to approximately 4.4 million residents, assuming an average household size of 4.4 people (as per national averages). Informal settlements, often in areas once designated for African workers, house a significant portion of the population. By 2013, around 160 informal settlements were the site of over 429,000 households (out of Nairobi's 1 million households), occupying less than 5% of the city's land[23].

Table 4:Population density changes in selected informal settlements from 2000-2020(Source: Adapted from [23])

Settlement Name	Area in hectares (ha)	Inhabitants/ ha in 2000	Inhabitants / ha in 2010	Inhabitants/ha in 2020	Net increase inhabitants/ha (2000-2020)
Huruma	78,14	614,44	911,93	1381,42	766,98
Kibera	287,13	439,43	671,88	985,7	546,27
Mathare	100,7	329,72	519,27	804,99	475,27
Dandora	182,15	248,61	403,18	585,31	336,7
Korogocho	99,74	281,84	481,86	588,93	307,09
Mukuru Kwa Njenga	133,21	155,26	257	358,74	203,48
Viwandani	167,11	140,22	91211,09	306,58	166,36

The population of Nairobi has experienced significant growth over the years, increasing from 293,000 in 1960 to 4.34 million in 2019. From 2015 to 2020, the city's annual growth rate averaged 3.81%, and it is projected to rise to 3.94% from 2020 to 2025. By 2015, Nairobi was home to 32% of Kenya's urban population, significantly more than Mombasa, the country's second-largest city, which only accounted for 9.1% of the urban population[23]. Population densities vary across Nairobi, with areas like Mathare reaching 68,941 people per square kilometre. Current trends in Nairobi include increased densification in informal settlements and tenements, rapid expansion in surrounding towns like Thika, and the development of satellite cities.

Based on current household trends, it is projected that Kenya will have approximately 15.9 million households by the year 2030. In the urbanized hub of Nairobi City alone, it is estimated that nearly 2 million additional housing units will be needed to adequately meet the demands of its expanding population by that time[49].

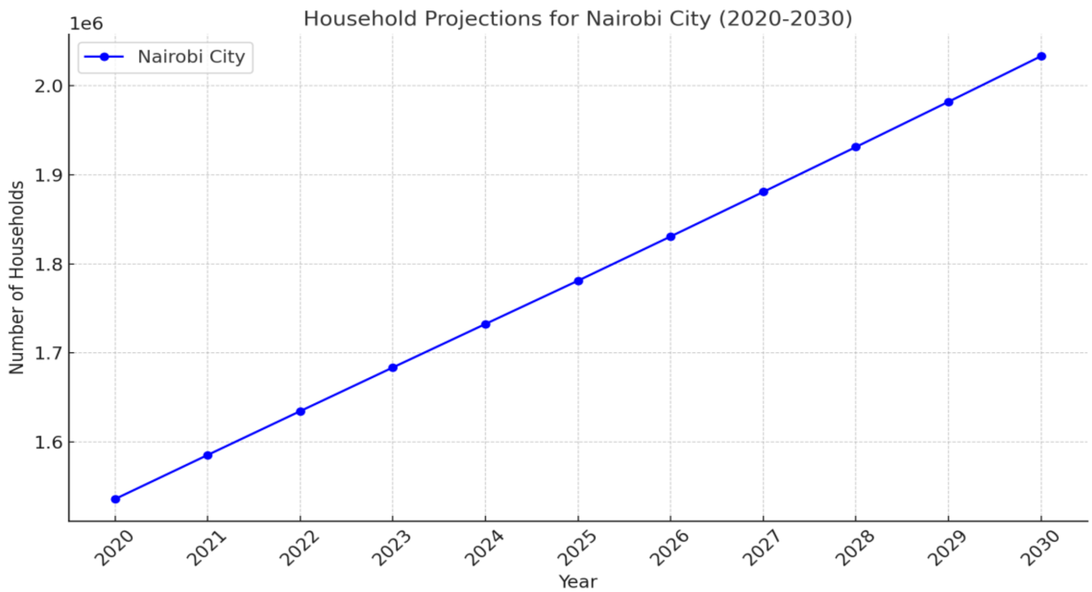


Figure 10:Projected Number of Households in Nairobi from 2020 to 2030 (source [49])

Abidjan Côte d'Ivoire

The Autonomous District of Abidjan, which is home to 21.5% of the population of Côte d'Ivoire holds significant demographic and economic importance. The rapid urbanization of Côte d'Ivoire has resulted in over half of the population now residing in urban areas, with 52.5% living in cities as of 2021. This is a significant increase from the 32% urban population in 1975. The urban transition, which took place between 1998 and 2021, has led to a growth in the number of cities with over 100,000 residents from 8 to 17[50]. Abidjan, as the country's economic centre, is the most populous city with 6,321,017 residents and the highest population density of 2,994 inhabitants per square kilometre. With a growth rate of 2.9% annually, it is projected that Abidjan's population will double in 24 years[50].

Abidjan, the economic capital of Côte d'Ivoire, is a prominent urban centre in sub-Saharan Africa in terms of both economic significance and population. Strategically located along the Gulf of Guinea on the Atlantic Ocean, this autonomous district spans 2,119 km^2, with bodies of water accounting for approximately 15% of its total area. Abidjan is composed of 13 municipalities and three sub-prefectures, accommodating a diverse population of six million people. Recognized for its cultural richness and diversity, Abidjan serves as a critical economic hub housing the majority of the country's industrial and financial sectors[51].

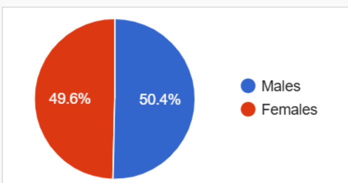
The rapid urban expansion in Abidjan has led to the unregulated occupation of undeveloped and non-buildable areas, causing significant changes to the city's housing landscape. These vulnerable neighbourhoods are home to approximately 20% of Abidjan's population, spread across 137 identified areas. Lacking crucial infrastructure such as clean water, proper sanitation, and waste collection services, these communities are facing increasing challenges. The growth in population has resulted in higher levels of waste production, leading to uncontrolled dumping that poses serious health and environmental risks[52].

Johannesburg, South Africa

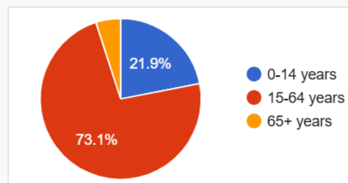
The city of Johannesburg is located in Gauteng, the smallest province in South Africa by land area, yet the most populous and urbanized. Johannesburg serves as an economic hub for both South

Africa and the African continent. The province's economy is dominated by financial services, government services, and manufacturing, contributing 2.2 trillion South African rand (33.1%) to South Africa's GDP.

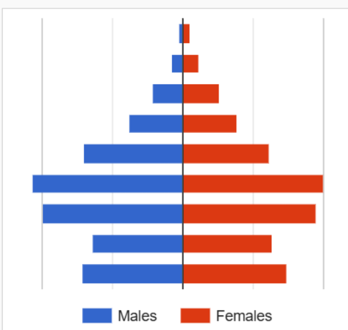
Johannesburg has historically experienced rapid population growth due to urbanization following the end of apartheid, with an average annual growth rate of 4.1% between 1996 and 2001, and 3.2% between 2001 and 2011. Projections suggested the city could reach 7 million inhabitants by 2040, however recent data from Census 2022 reveals a significant slowdown. Gauteng's province overall growth rate currently stands at 2.0%, slightly above the national average but trailing behind provinces like the Western Cape (2.4%) and Mpumalanga (2.3%). Notably, Johannesburg's current growth rate is just 0.8%, indicating it is no longer one of the country's fastest-growing major cities[53],[54].



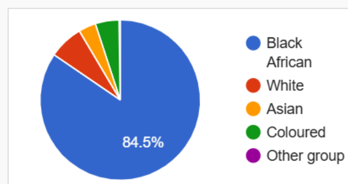
Gender (C 2022)	
Males	2,419,151
Females	2,384,111



Age Groups (C 2022)	
0-14 years	1,053,365
15-64 years	3,510,597
65+ years	239,147



Age Distribution (C 2022)	
80+ years	37,860
70-79 years	100,965
60-69 years	238,394
50-59 years	385,572
40-49 years	661,617
30-39 years	1,036,785
20-29 years	973,063
10-19 years	638,757
0-9 years	730,096



Population Group (C 2022)	
Black African	4,053,803
White	333,651
Asian	167,363
Coloured	229,528
Other group	11,810

Figure 11:City of Johannesburg Urban Population Distribution(Source: [55])

Johannesburg's urban population is distributed unevenly, which includes townships like Soweto, accommodating over a third of the city's residents. This area is experiencing growth fuelled by informal settlements. The population density has increased from 2,000/km^2 in 2002 to 2,924/km^2 in 2022, surpassing other Gauteng metros such as Ekurhuleni and Tshwane (Pretoria). However, density levels vary significantly, with some neighbourhoods exceeding 30,000 people/km^2. Urban sprawl persists due to the lack of a clear urban boundary in the city. Wealthier residents tend to move to eco-estates, while economically disadvantaged groups often cluster in central areas, particularly in informal settlements. Governance challenges include issues such as non-payment for electricity in certain townships, which is worsened by Eskom's financial difficulties and increasing electricity costs. Illegal connections remain a widespread problem, putting strain on public services and potentially leading to social unrest. It is crucial for Johannesburg to address these issues in order to ensure sustainable urban development and improve the quality of life for all residents[55],[56].

Kigali, Rwanda

The City of Kigali, the capital of Rwanda, is strategically situated in the centre of the country and covers 730 km^2, encompassing three districts: Gasabo (429.3 km^2), Kicukiro (166.7 km^2), and Nyarugenge (134 km^2). According to the fifth Rwanda Population and Housing Census (RPHC5), Kigali is home to 1,745,555 residents and is organized into 35 administrative sectors, 161 cells, and 1,155 villages. Kigali shares borders with Gicumbi and Rulindo Districts in the Northern Province, Bugesera and Rwamagana Districts in the Eastern Province, and Kamonyi District in the Southern Province. In the past 25 years, Kigali has experienced rapid growth and has emerged as one of Africa's fastest-growing cities, with an urbanization rate of 4% annually. The city also plays a significant role in Rwanda's economy, contributing over 41% of the country's GDP[57].

Since 1990, Kigali has undergone considerable growth and expansion despite challenges posed by its geographical and climatic conditions. A land reform effort initiated in 2009 has improved access to essential services, surpassing regional averages. However, 60% of Kigali's population resides in informal settlements, many of which are exposed to climate-related risks due to their landlocked nature. Presently, 63% of the city's settlements lack proper planning and infrastructure, resulting in substandard living conditions[58].

Vision 2050 is Rwanda's long-term development framework aimed at transforming the country into an upper-middle-income nation by 2035 and a high-income nation by 2050. It focuses on achieving inclusive economic growth, fostering sustainable urbanization, and improving the quality of life for all Rwandans. In the context of urbanization, Vision 2050 emphasizes the need for well-planned urban centres that drive economic development, reduce inequality, and enhance resilience to climate change. According to this vision, Rwanda's urban population is projected to grow significantly, from 27.9% of the total population in 2022 to 70% by 2052. This rapid urbanization means the urban population is expected to quadruple over the next 30 years, rising from 3.7 million in 2022 to 16.6 million under the medium-growth scenario. The medium-growth scenario refers to the population projection based on moderate assumptions about fertility, mortality, and migration rates, representing a middle-ground estimate between low and high growth trajectories. In contrast, the rural population is projected to grow slightly, from 9.5 million in 2022 to 9.6 million by 2026, before gradually declining to 7.1 million by 2052, also based on the medium scenario[59].

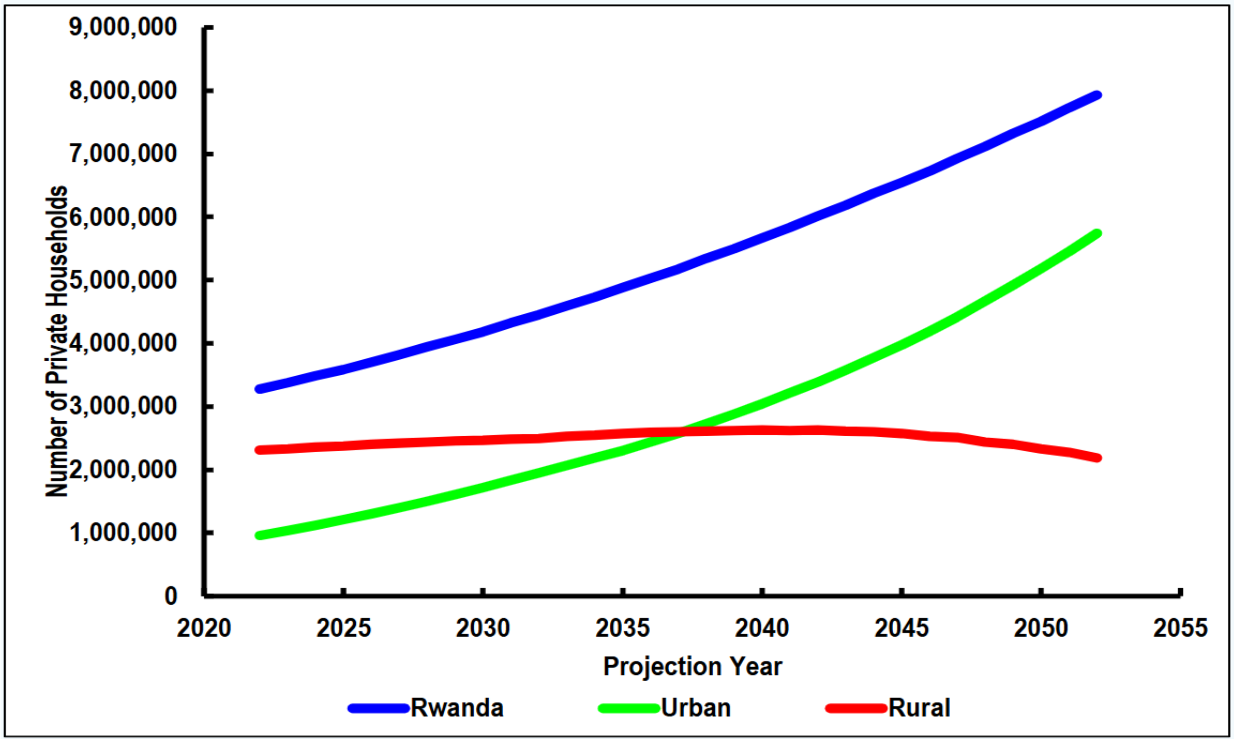


Figure 12:Projection of private housing by place of residence in Rwanda from 2022 - 2052(Source: [59])

Maputo, Mozambique

Maputo Municipality spans 347 km^2, with approximately 117.6 km^2 urbanized and an estimated population of 2.57 million in 2024, projected to reach 5.2 million by 2025. About 33% of its land is designated for residential use, reflecting rapid population growth driven by high birth rates and immigration. Urban areas, covering 8,400 hectares, are densely populated with an average of 70 inhabitants per hectare, particularly concentrated in Municipal District No. 1 (14%). Despite this urban expansion, infrastructure remains inadequate, highlighting an urgent need for improved planning and land management to enhance access to essential services such as water and drainage systems[60].

Maputo City itself covers 346 km^2 with a population of 1,133,323 in 2024, expected to grow to 1,251,559 by 2050, with a high population density of 3,275 inhabitants per km^2. A major challenge is the limited availability of housing for young adults, prompting many to seek residence in the city's outskirts. The city's youthful demographic and rising birth rates further strain urban planning efforts, underscoring the need for sustainable spatial development to accommodate its rapidly evolving landscape[60].

Lusaka, Zambia

Lusaka Province, situated at the heart of Zambia, stands as the nation's most densely populated and urbanized region. Spanning 21,986 square kilometres, it may be smaller in size compared to other provinces, but it is home to a large and continually growing population. As of 2022, Lusaka Province boasted a population of over 3 million, solidifying its position as the most populous area in the country. With a high urbanization rate of 81.5% as shown in **Figure 13**, most residents reside in urban areas, primarily within the provincial capital, Lusaka City, which also serves as Zambia's national capital. Consequently, Lusaka Province serves as the administrative, economic, and cultural nucleus of the nation[61].

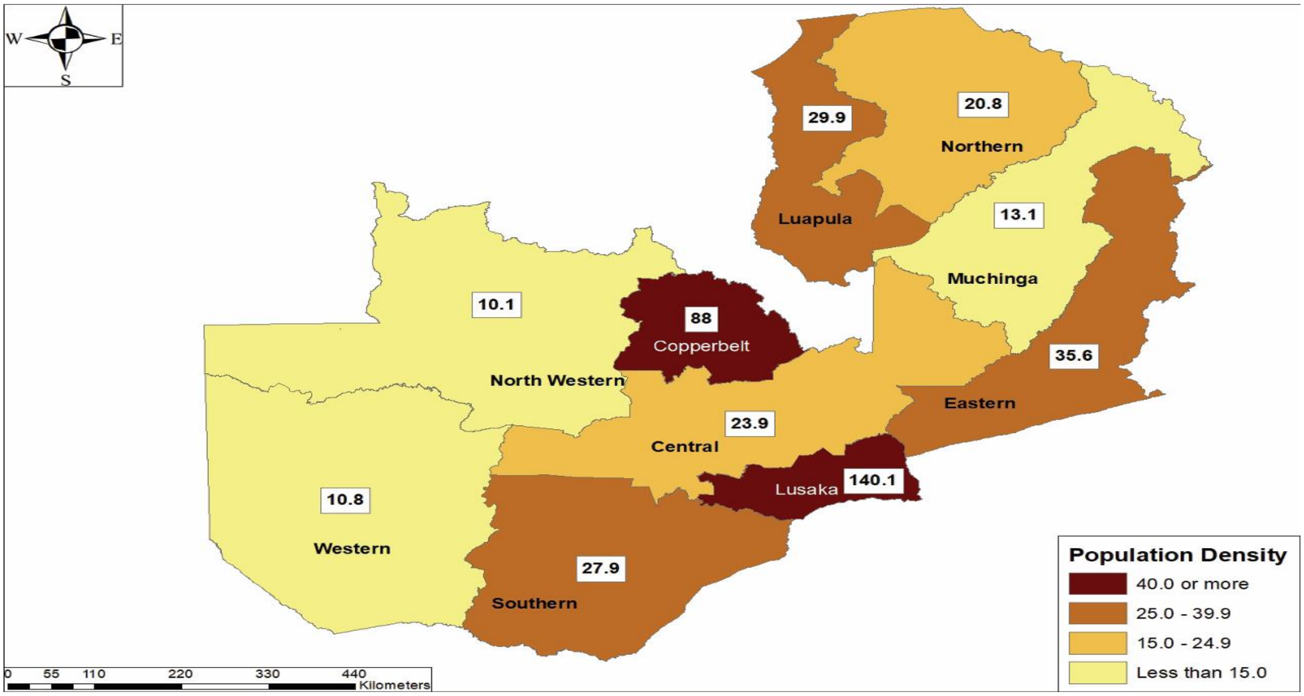


Figure 13:Population Density by Province in Zambia for 2022 (Source: [61])

Lusaka Province has witnessed significant population growth, increasing from 2,191,225 in 2010 to 3,079,964 in 2022, reflecting an average annual growth rate of 2.88%. The province also records the smallest average household size in Zambia at 4.5, encompassing a total of 687,923 households. Its population density stands at an average of 140.1 people per square kilometre, with notable disparities across districts. Urban areas like Lusaka District exhibit a high population density of 5,272.9 people per square kilometre, while rural districts such as Rufunsa and Luangwa have much lower densities, at 8.7 and 9.3 people per square kilometre, respectively[61].

Over the past two decades, Lusaka has experienced a substantial increase in the number of residents residing in informal settlements, which are present in 94 townships or compounds throughout the city. Approximately 38.3% of the city's residential land is classified as informal, with 22 areas having more than a quarter of their land designated as informal or atomistic, highlighting the widespread nature of informal urbanization in Lusaka. As of 2020, an estimated 1.4 million people, representing nearly 62% of Lusaka's total population, were living in these informal conditions. The density of these settlements has also increased significantly, from 126 people per hectare in 2000 to 148 people per hectare by 2020, resulting in a density of approximately 1,480 people per square kilometre. This density is notably higher than the overall built-up density of the city, which is approximately 95 people per hectare[40].

3.0 Urban Electricity Access in Sub-Saharan Africa Today

3.1 Current Electricity Access Rates

The United Nations Sustainable Development Goal 7 (SDG7) aims to ensure access to affordable, reliable, sustainable and modern energy for all by 2030. However, globally, 759 million people still do not have access to electricity[62]. As of 2024, approximately 43% of Africa's population, equating to about 600 million people, lacked electricity access, with 590 million of these individuals residing in SSA [63], [64]. Nigeria, the Democratic Republic of Congo, and Ethiopia collectively account for one-third of the population in sub-Saharan Africa without electricity, amounting to 200 million people[65]. From 2013 to 2020, some Sub-Saharan African countries made notable progress, but this progress was reversed during the COVID-19 pandemic. Studies suggest that if current trends continue, over half a billion people could still lack access to electricity by 2030. Achieving universal access will require significant scaling up of innovations in both off-grid and centralized grid systems.

Over the period from 2012 to 2022, Africa's electricity generation capacity has grown at an average rate of just over 2% per year, which is below the global average of 2.5%. At the same time, the population has grown at an average rate of 2.42% annually over the past 30 years. This means that the increase in energy generation is barely keeping pace with the growing population. As a result, the energy deficit remains, with more than half of Africa's population lacking reliable access to electricity.

As a region, access to electricity in urban and peri-urban areas in SSA is the lowest, with over 20% of urban populations lacking access to electricity. In addition, annual electricity consumption per capita is 487 kWh, ranking among the lowest globally compared to other regions, trailing both low- and middle-income regions, which average 1,927 kWh and 3,128 kWh, respectively. The low levels of consumption are associated with limited productive uses of energy, which impact socio-economic development at both the household level and the regional level[66]. They also hinder the provision of public services, quality of life, and the adoption of new technologies in sectors such as education, agriculture, and finance[67].

Access to electricity in Urban and Peri-Urban Areas

In Africa's urban areas, electricity access improved from 70.4% in 1991 to 76.0% by 2014. However, rapid population growth in urban regions offset these gains, leaving approximately 110.6 million people without electricity in 2014[68]. As of 2020 78% of populations living in urban areas had access to electricity, the fastest growth among all regions. However, this progress can largely be attributed to the region's low urban electrification rates at the start of the period. In addition, despite the improvement, 110 million people in urban areas in Africa remain without access to electricity, with 99 million of them residing in SSA, highlighting the ongoing challenge of achieving universal energy access in the region[69]. **Figure 14** shows the percentage of the population in urban settings without access to electricity In SSA by country.

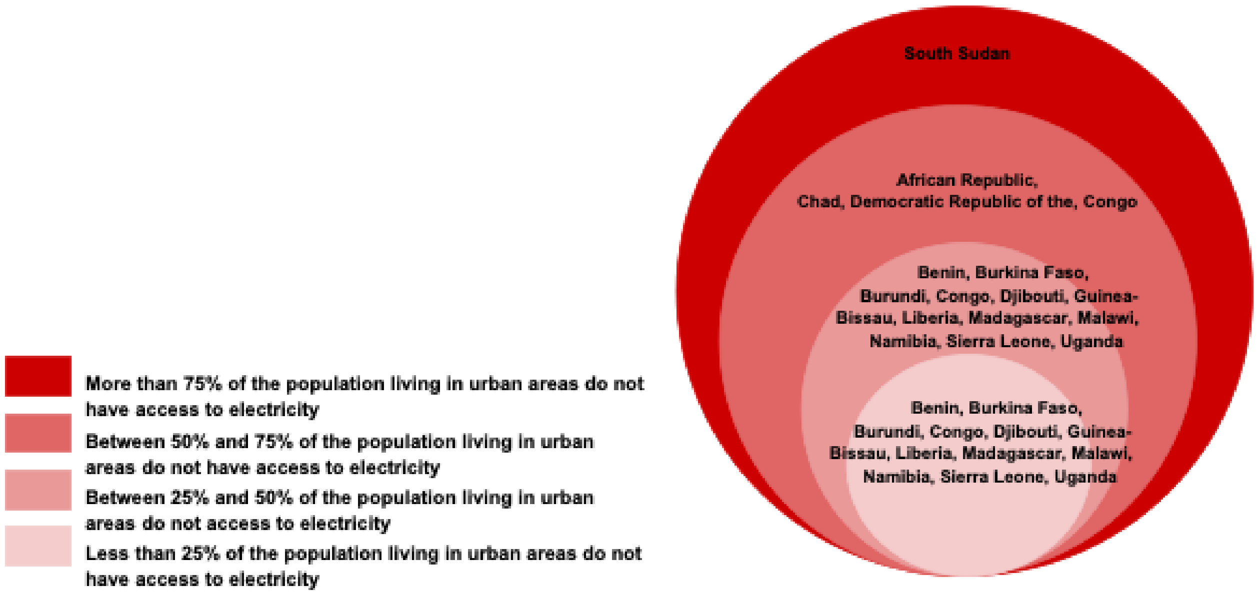


Figure 14:Electricity access rate across Sub-Saharan Africa (Source: adapted from [70])

South Sudan has the lowest levels of access to electricity, with only 5.4% of the population connected to the grid. In urban areas, this figure rises to just 15%. This limited access is primarily due to the country's reliance on imported diesel for electricity generation[71]. Additionally, persistent subnational violence, weak public resource management, and ongoing political contestation have significantly hindered development efforts[35]. In addition, in some countries, households and commercial buildings with electricity report significant challenges with frequent power outages and load shedding. For example, in Nigeria, 51% of connected households experience intermittent electricity supply. This unreliability is a critical issue as it diminishes the perceived value of electricity access for potential new customers. Furthermore, many consumers justify their failure to pay bills due to unreliable service. Blackouts, which are complete power outages, are not the only concern; brownouts, periods of reduced voltage, can also affect reliability. During brownout, the power supply may be sufficient for basic lighting but inadequate for appliances like fans or refrigerators. These disruptions, along with limited capacity, reduce the benefits of electricity service, which in turn lowers consumer willingness to connect. A clear and strong link exists between the reliability of electricity and the rate of household connections[67].

3.2 Challenges on Access to Electricity in Urban and Peri-Urban Areas in Sub-Saharan Africa

By 2040, more than half of Africa's population is projected to reside in urban areas. This demographic shift could make it more cost-effective to provide electricity to a larger portion of the population, as connecting urban areas is generally less expensive[67]. This is largely because more than one in six people in Sub-Saharan Africa lacking electricity live directly under the grid. According to a recent World Bank report on African infrastructure, grid connection rates are high in a few countries, such as South Africa, Nigeria, Gabon, and Cameroon, but remain below 50 percent in most other countries across the region[1].

[1] World Bank, 2023, Trade infrastructure financing in Africa: An exploration of geopolitical funds for private sector participation

Rapid urbanization puts stress on urban infrastructure, and when resources are limited for expanding services, people often resort to low-cost survival options. Illegal connections are common in informal settlements, as the nature of these areas discourages distributors from connecting households and businesses to electricity. Such dwellings often fail to meet minimum safety standards. Most electricity distributors rely on overhead connections, but the lack of passable roads, safety concerns, and the prevalence of illegal connections deter them from implementing underground connections. In this section we shall discuss both supply and demand challenges to electricity access focusing on urban and peri-urban areas.

Box 1

Clarification of the misconception that electricity access is primarily a rural issue

Lack of electricity is not solely a rural issue; metropolises, cities, medium-sized towns, secondary towns, and small urban settlements all face challenges in accessing safe and reliable electricity, only a few countries have been able to achieve universal access to electricity in urban areas, including Comoros, Mali, and Seychelles. Peri-urban areas in many large African cities, often marked by informal settlements, find themselves in a "transitional zone," where they lack access to both the city grid and rural electrification programs[72]. Though still, in rural sub-Saharan Africa, electricity access grew modestly from 17% in 2010 to 28% in 2020, this falls far short of the global rural average of 83%[69].

Peri-urban areas often have lower socio-economic conditions compared to urban centres, making utilities hesitant to prioritize or extend services to these regions. This reluctance stems from concerns about payment challenges among low-income users, the high costs of electricity connections deterring potential customers, and the limited energy consumption of households, which generates minimal revenue. Although peri-urban areas share some similarities with rural regions, they differ in population density and economic activities, preventing them from being classified as entirely rural. In cases where electricity management is divided among agencies based on geographic scale, such as separate entities for urban and rural areas, jurisdictional conflicts may arise. Furthermore, peri-urban areas are often marginalized in favour of established urban centres, where most investments are focused.

3.2.1 Supply Side Challenges

Rapid population growth in cities creates significant pressure on electricity distribution systems. It is common to see overloaded transformers or other grid components failing, resulting in poor power quality for connected users and forcing electricity distribution system operators (DSOs) to delay new connections due to insufficient resources to upgrade the system for reliable and quality connections. Moreover, many SSA governments face financial challenges due to mounting public debt, which has accelerated in recent years and raised concerns about a potential debt crisis[66].

Planning Challenges

Rapid urbanization in Africa presents significant challenges for electricity access, particularly in urban areas where informal settlements are prevalent. This situation is exacerbated by poor planning and inadequate energy infrastructure, leaving millions without reliable electricity.

Existing electrification strategies often lack integration between grid and off-grid solutions. For example, in Kenya, separate planning processes for different agencies fail to systematically expand coverage across both types of services. Additionally, bureaucratic hurdles such as obtaining wayleaves and rights of way delay project implementation and increase costs[73].

Urban grid infrastructure in many African cities was originally developed during colonial rule, with centralized grids focused on the colonial capitals and neighbourhoods[74]. This led to the creation of segregated cities, where modern neighbourhoods were designated for colonial settlers, while indigenous populations were confined to other parts of the city. This historical pattern of infrastructure development still impacts the present, with heavy infrastructure concentrated in city centres and former colonial sectors, leaving peri-urban areas less developed. Informal settlements are often situated on public land, city riverbanks, and flood-prone areas. In Nairobi, Kenya, the Mathare community faces a significant lack of investment in infrastructure and services. Located in a flood-prone area, the slum presents challenges in providing basic services such as electricity. **Figure 15** illustrates a section of Mathare and highlights the difficulties associated with establishing a traditional grid connection.

Figure 15: Mathare informal settlement in Nairobi (Source: Edwin Ndeke. 2024. The Guardian)

Missing Distribution Lines and Systems

Many SSA countries have faced challenges in developing the necessary infrastructure to ensure energy security. For instance, Nigeria's energy sector has significantly declined due to weak and ageing infrastructure. Between January 2010 and June 2022, the country experienced 222 partial or total grid collapses, compounded by factors such as outdated equipment, and limited operational transmission lines[75]. In Kinshasa in the Democratic Republic of Congo (DRC), with access rates at 44%, power blackouts and electricity shortages occur frequently, this situation is fuelled by fast-rising demand for power and ageing infrastructure[76]. The grid operator SNEL is currently unable to provide consistent electricity to all of Kinshasa due to limited production capacity at Inga I and II dams, due to the poor condition and lack of maintenance of the hydro power plants, transmission and distribution lines[77].

Funding Challenges

Africa receives only about 3% of global energy investments and just 2% of global spending on clean energy[78], [79]. These low levels of investment not only account for the slow growth in energy supply over recent years but also conceal the substantial disparity in how global capital is allocated. The World Bank estimates that approximately $800 billion will be needed for Africa to meet Sustainable Development Goal (SDG) 7 by 2030. Without significant investments in power generation and transmission infrastructure, over 670 million people in sub-Saharan Africa could remain without electricity by the end of the next decade[65]. From 1990 to 2013, only $45.6 billion was invested in power generation across Sub-Saharan Africa, averaging less than $2 billion annually. Notably, over 20% of this investment was concentrated in South Africa alone[80].

The scarcity of public funding and limited private sector involvement in transmission and distribution projects are worsening grid inefficiencies and capacity constraints. Current grid systems experience significant losses that impede the efficient use and distribution of electricity from existing power plants. Furthermore, the inadequate grid capacity limits opportunities for new investments in electricity generation. These inefficiencies also contribute to a decline in customer willingness to pay, further exacerbating the financial challenges faced by distribution system operators (DSOs). This combination of challenges highlights the urgent need for cooperation between the public and private sectors to address grid infrastructure gaps, which are essential to overcoming Africa's energy deficit[81].

Unsustainable Business Models

To increase electricity uptake more effectively, challenges stemming from below-cost tariffs must be addressed. In many African countries, connecting additional households is unprofitable, reducing utilities' motivation to simplify the connection process and eliminate barriers to access. Evidence indicates that distribution utilities often incur losses when adding new consumers at lifeline tariffs, especially without factoring in connection costs or additional charges. In many cases, utilities cannot remain financially viable with connection fees below $200 unless tariffs are increased[67]. This situation leads to high connection costs and low access rates, driven by regulated tariffs that are insufficient and low consumption levels.

Even where access is achieved, electricity consumption in Africa remains minimal, providing limited benefits to users and preventing utilities from recovering costs. For instance, in 2014, per capita residential electricity consumption averaged just 438 kilowatt-hours, enough to power a 50-watt light bulb continuously for one year. Both access rates and consumption levels fall short when compared to other regions with similar income levels[67].

Low Reliability

Frequent power outages can deter households from connecting to the grid. Reliability plays a significant role in influencing consumer behaviour, as many firms and households already connected to the grid in Sub-Saharan Africa experience regular blackouts. Research shows that a consistent power supply encourages more households to connect. A study utilizing the World Bank's Doing Business Index, which assesses the conduciveness of a country's regulatory environment for private sector operations, analysed power outage metrics[2]. The findings demonstrate a negative correlation between blackouts and urban electrification rates. In essence, areas with dependable power supply tend to have higher connection rates among households situated near the grid.

[2] World Bank, 2020: Comparing Business Regulation in 190 Economies

Electricity supply reliability remains a significant challenge in Africa. The percentage of businesses experiencing power outages is higher than in any other region (**see Figure 16**). To cope with these disruptions, most enterprises rely on generators, a practice that is more common in Africa than in other regions. In Nigeria, fewer than 20% of households report having electricity available most of the time, and around 51% experience electricity only occasionally. Addressing these issues will require substantial investment to achieve a reliable power supply. Nigeria alone could require up to $100 billion over the next two decades, with the cost of achieving universal energy access being even greater. While the country boasts nearly 100% grid coverage especially in urban areas, reliability is far different[75]. Even when electricity is available, brownouts are common, further restricting the effective utilization of power by end users[67].

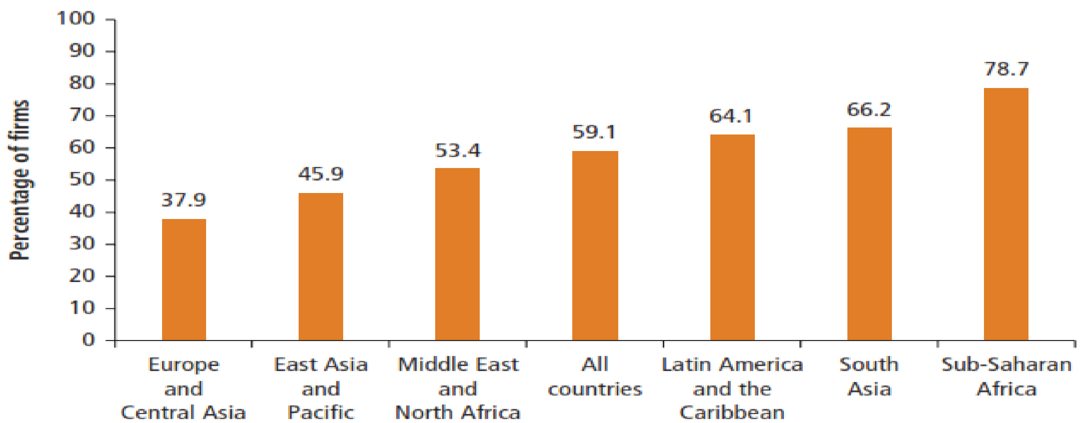


Figure 16:Percentage of firms experiencing electrical outages (Source: [67])

One possible explanation is that countries experiencing frequent blackouts tend to have weak infrastructure and limited capacity to expand connections. Another reason could be that households are less willing to connect to the grid if the electricity supply is unreliable. This is logical: when power provision is inconsistent, the value of investing in an electrical connection becomes uncertain. Furthermore, unreliable grids force households to continue using inferior energy sources, such as wood fuel for lighting. In such cases, even connected households may end up paying for two energy sources, as utilities often impose a fixed monthly charge. A study in India has shown that this additional cost can discourage households from connecting to the grid[82].

Power Theft

Various organizational challenges, such as corruption, power theft, inefficient bill collection, complex interconnection processes, and service delivery issues, hinder energy access in peri-urban areas. In countries where electricity access is limited, the combination of energy poverty and proximity to the grid often increases the likelihood of such vices including illegal connections[72]. In 2020 and 2021, Uganda experienced a rise in illegal connections and vandalism of electricity infrastructure. Of the 17.5% recorded power losses, 8.3% were attributed to electricity theft. Electricity theft poses significant threats to energy security in three keyways: (i) it can disrupt the entire electricity system by causing load instabilities, (ii) it leads to financial losses for utility companies, potentially deterring future energy investments, and (iii) it lowers the quality of electricity supplied to legitimate consumers[83].

Low Adoption of Innovative Energy Solutions

Many sub-Saharan African countries already have extensive experience in electricity innovation and deployment. However, state-owned utilities sometimes resist new energy technologies, particularly those that do not align with their existing assets and expertise. Despite this, progress has been made in the adoption of new energy technologies in some countries. For instance, in Kenya, the integration of renewable electricity has enabled the country to provide electricity access to over three-quarters of its population, including 97.5% of those in urban areas[84].

There are numerous energy technologies, such as solar home systems, mini-grids, virtual power plants (VPPs), energy kiosks, and battery energy storage systems (BESS). These technologies, combined with innovative business models like Pay-As-You-Go, have significant potential but remain underutilized, particularly in urban areas. Emerging technologies such as geospatial tools and remote monitoring can help assess the true scale of the electricity access gap and improve service delivery by providing real-time data on usage and outages[85].

3.2.2 Demand side challenges

Demand-side challenges in sub-Saharan Africa pose equal, if not greater, obstacles to electrification compared to supply-side constraints. A significant proportion of households located near the electricity grid remain unconnected, with median connection rates at just 57% across 20 countries based on comparable Living Standards Measurement Study (LSMS) data. Low connection uptake is influenced by the maximum amount households are willing to pay. For instance, in Rwanda, when presented with three different price and payment options, 88% of households declined all the options[67]. The challenges surrounding electricity demand are further discussed below.

Low Ability to Pay

High connection charges and complex connection processes often serve as significant barriers to electricity access and highlight a critical policy opportunity to boost uptake. In many countries, connection charges are disproportionately high relative to average income levels. Evidence from 10 African countries examining recently connected households reveals additional challenges: (1) connection processes are often standardized and fail to address the unique constraints faced by low-income households; (2) the process involves lengthy waiting periods, often exceeding 10 weeks; and (3) while connection costs are typically viewed as fixed, variations due to wiring and transaction expenses create regressive impacts, making affordability more difficult for poorer households[86].

Irregularity and unpredictability of income flows also affect households' willingness to connect. For households with inconsistent income streams, even small recurring payments can be challenging. Prepaid meters or 'pay as you go' can help address this issue, and introducing flexible payment options that align with income variability could further support accessibility[86]. For instance, in Liberia, electricity tariffs were 51 cents per kWh in 2014, more than three times the median tariff in sub-Saharan Africa. That same year, Liberia's urban electrification rate stood at just 15%[82].

Minimum Connection Standards

Traditional AC (alternating current) electricity connections often require minimum housing standards that many homes, especially in the low-income areas in urban set-ups fail to meet. Alternative technologies, such as ready boards(which are pre-wired electricity distribution panels designed for informal or substandard housing), allow for connections to substandard housing. Greater coordination between housing and electricity regulators could ensure building permit requirements align with standards for electrical connections, facilitating broader access[67].

Behaviours Change Caused by Consistent Power Outages

Reliability of electricity supply plays a significant role in influencing end-user behaviour. Frequent blackouts, which are a common experience for many grid-connected firms and households in Sub-Saharan Africa, discourage others from connecting. Research indicates that a dependable power supply leads to higher grid connection rates[82].

Box 2

"Under the Grid" Issue: Analysis of households near electricity grids but lacking connections.

Although most countries have grid lines, data from the Living Standards Measurement Study since 2010 reveal a median uptake rate of only 57%. This suggests significant potential for improvement if challenges related to demand are carefully identified and effectively addressed[67]. Beyond pure cost barriers, urban communities often experience persistent and pervasive challenges due to economic and political remoteness (as opposed to geographic remoteness) and are neglected by large-scale public investment schemes[70]. Simple measures such as offering more affordable and convenient payment options, improving local infrastructure, and engaging customers creatively in marketing and bill collection can significantly boost electricity access and improve customer retention[87].

The World Bank has conducted studies indicating that many households in Sub-Saharan Africa live near the electrical grid but are not connected, raising important questions about the demand for electricity and related services. These households may also represent an opportunity for faster progress in expanding access to electricity[67], [82].

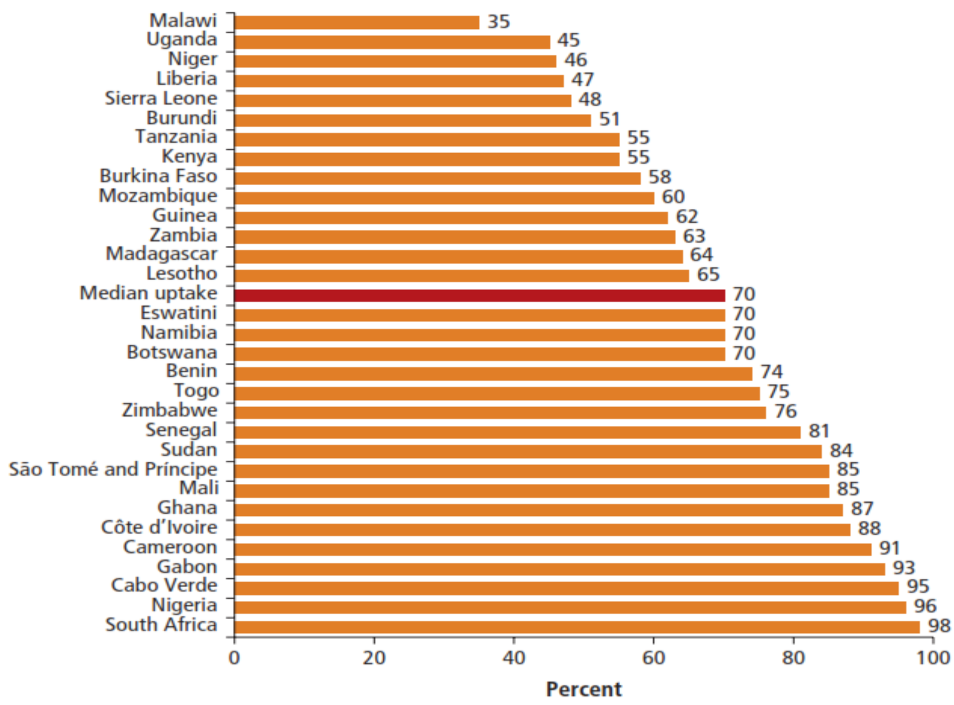


Figure 17:electricity uptake (households living under the electrical grid that have a connection (Source: [67])

3.2.3 Utility Vicious Cycle

The demand and supply challenges discussed above creates a vicious cycle on the efforts of reaching 100% electricity access in urban and peri urban areas (**see Figure 18**). This cycle perpetuates low electrification rates despite the proximity of many urban populations to existing grid infrastructures.

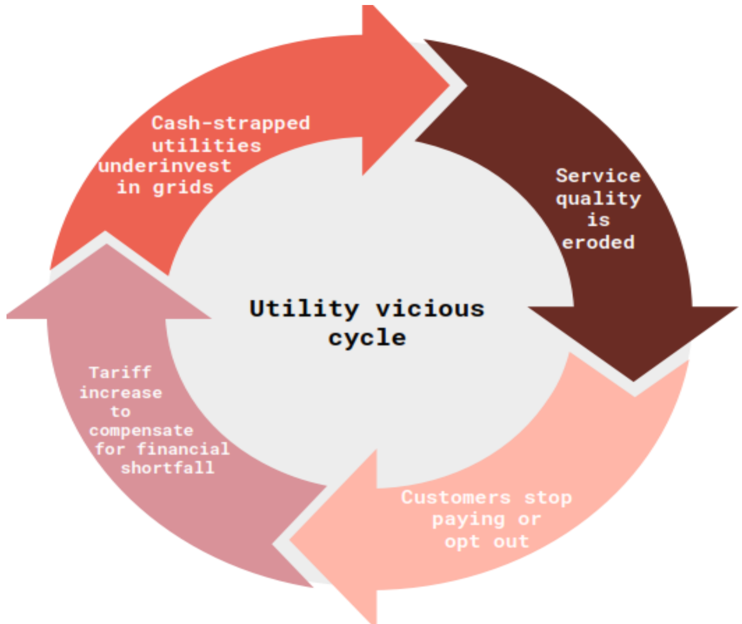


Figure 18:Utility Vicious Circle(Source: [88])

The vicious cycle surrounding electricity generation and consumption is complex but not insurmountable. By making strategic investments in programs like last-mile connectivity, adopting innovative and smart technologies, upgrading infrastructure, enhancing efficiency, and supporting policy initiatives, we can break this cycle and move toward a more sustainable path that will ensure 100% access to electricity. As discussed in the preceding sections several reasons bring about this vicious cycle.

Financial and Institutional Barriers
Majority of utilities in SSA struggle with high debt burdens, inefficiencies, and funding gaps, which limit investments in grid expansion and maintenance. Many state-owned electricity providers operate below cost recovery, resulting in low investment in new connections. Data from the World Bank Utility Performance and Behavior in Africa Today (UPBEAT) analysis shows that only 14 utilities (vertically unbundled and bundled) in 11 countries (Côte d'Ivoire, Eswatini, Gabon, Kenya, Lesotho, Mauritius, Namibia, Seychelles, Sierra Leone, Uganda, and Zambia.) can post a net profit[89].

The Demand-Side Trap
High connection fees make it difficult for low-income populations to afford consistent power. Additionally, persistent blackouts and poor service quality discourage households and businesses from connecting, further reducing electricity uptake.

Balancing Economic Interests and the Public Good
Many urban and peri-urban households have low energy consumption, generating minimal revenue for utilities. As a result, utilities lack incentives to simplify connection processes or lower costs.

Stagnation in Innovative Energy Solutions
While SSA has seen the rise of solar home systems, mini-grids, and Pay-As-You-Go models, these solutions remain underutilized in urban areas.

3.3 Variability in Electricity Uptake Rates Across Countries

Electricity uptake rates vary significantly across Sub-Saharan African countries, influenced by factors such as economic growth, infrastructure development, and policy frameworks. Understanding these disparities provides insight into the challenges and opportunities for expanding energy access across the region. **Figure 19**, illustrates electricity uptake trends from the 1990s to the mid-2010s in Nigeria, Cameroon, Malawi, Rwanda, and Kenya, highlighting distinct patterns of growth and regional differences.

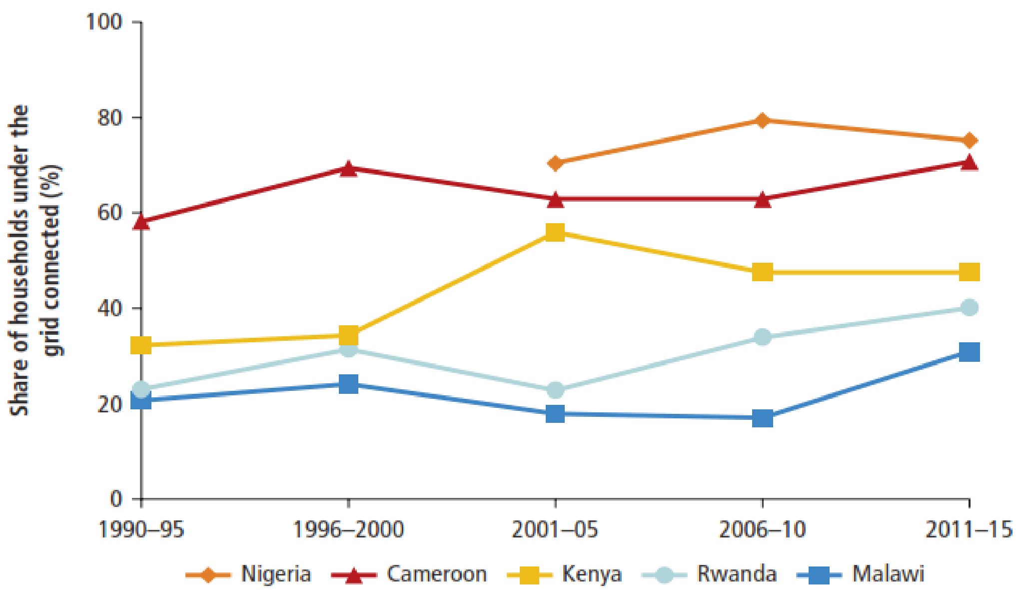


Figure 19: Electricity uptake Nigeria, Cameroon, Malawi, Rwanda, and Kenya (Source: [67])

A detailed examination of the electricity uptake trends in Nigeria and Kenya is provided in the following section, highlighting the unique drivers, challenges, and progress observed in each country.

Nigeria
With less than six years remaining to achieve SDG 7 which aims for universal access to clean energy, Nigeria still has over 86 million people without electricity, the highest figure globally. In rural regions, electricity access is available to less than one-third of the population. Although urban areas perform better with an access rate of 89%, persistent gaps between electricity supply and demand, coupled with outdated infrastructure, lead to frequent outages and poor power quality[90]. As a result, Nigerians and their businesses spend almost $14 billion annually on inefficient generation that is expensive ($0.40/kWh or more), of poor quality, noisy and polluting.

Despite the grid challenges in Nigeria, uptake rate is very high, with 9 in 10 households under the grid opting for connection. The numbers are also quite high in rural areas, suggesting that supply-side barriers, including generation capacity and extension of infrastructure, are more of a challenge than demand, although electricity theft and bill payments must be addressed[67]. ESI Africa recently reported that according to Nigeria's National Bureau of Statistics (NBS) the total customer numbers increased from 11.47 million in the second quarter (Q2) of 2023 to 11.71 million in the third quarter (Q2) of 2023 representing an increase of 2.08%[91].

Kenya

In 2014, in a study on electrification barriers in rural Kenya, it was revealed that half of the unconnected households were located “under grid,” within 200 meters of a low-voltage power line, suggesting that connecting them could have been relatively affordable[92]. Despite significant investments in grid infrastructure, electrification rates remained low. The research emphasized the need to target "last mile" connections in these communities to tackle energy poverty effectively. To maximize the potential of existing grid infrastructure and achieve economies of scale, the study recommended adopting subsidies and innovative financing approaches[92]. It was noted that one key barrier to electricity connection was the cost of connecting a household which was estimated at USD $400, which was nearly a third of the average annual per capita income and over four times the average amount that households were willing to pay for the service.

In 2015, the government introduced the Last Mile Connectivity Program with the goal of achieving universal electricity access by 2020. Structured in phases and guided by international best practices, the initiative emphasised cost-efficiency through economies of scale. The program aimed to deliver five million new connections within five years, prioritizing informal urban settlements and low-income rural households[93]. As a result, Kenya has become one of the fastest-improving countries in meeting Sustainable Development Goal (SDG) 7 on electricity access. By April 2022, the national electricity access rate had risen to 76%, up from 26% in 2013. In Nairobi, electricity access increased from 72.4% in 2009 to 96.7% in 2019 as shown in **Figure 20**[94].

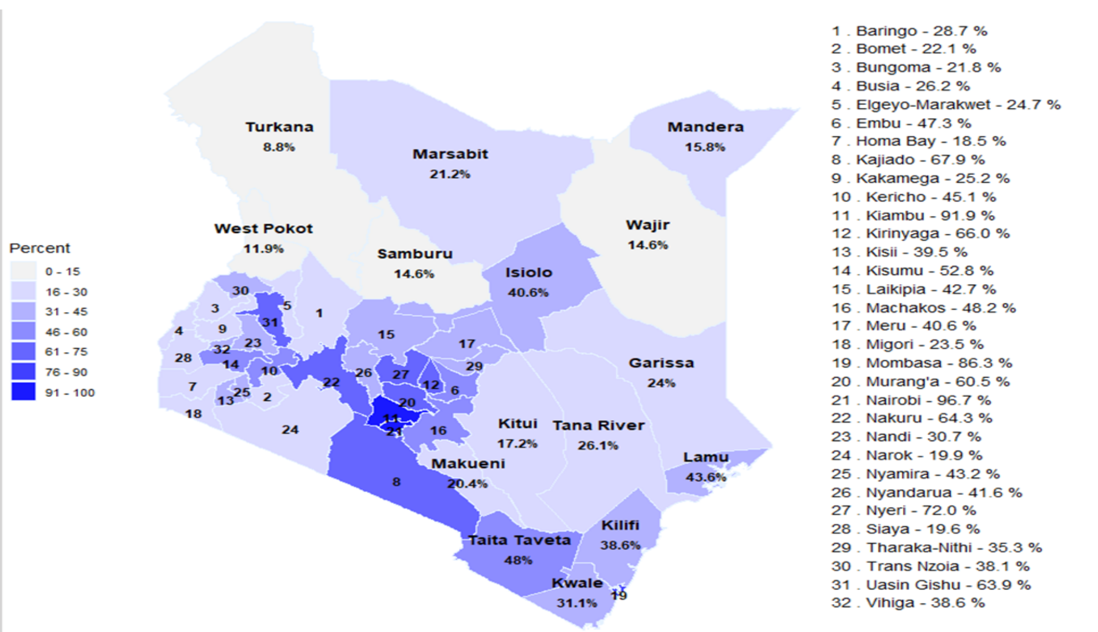


Figure 20:The map above shows household access to electricity in 2019 in Kenya(Source: [94])

3.4 The Need for Substantial Investments in Access to Electricity and Service Reliability

To bridge the energy access gap, SSA requires an estimated $28 billion in annual investments through 2030. Approximately $13 billion is required for mini-grid systems, while an estimated $7.5 billion must be allocated for grid expansion and $6.5 billion for off-grid solutions[95]. Attracting this level of investment necessitates creating an enabling environment through supportive policies and regulations that foster private sector participation and innovation. With over half of urban dwellers living in slum-like conditions without reliable electricity connections, targeted investments in urban electrification are essential. Addressing affordability and connection legality will help integrate these populations into formal energy systems[85].

Innovative solutions are essential to connect these communities to reliable and sustainable energy sources. Initiatives like the SEED project in Kenya aim to create comprehensive energy solutions tailored for informal settlements. These projects focus on integrating renewable energy technologies while promoting community awareness and capacity building[96]. Similarly, a study conducted in Namibia underscores the viability of hybrid systems in such contexts. In the Havana informal settlement of Windhoek, a hybrid system combining solar, diesel, and battery storage emerged as the most cost-effective off-grid renewable energy solution. This highlights the potential of hybrid systems to meet energy needs in informal and peri-urban areas with characteristics like rural settings[97].The investment required for energy infrastructure in SSA is substantial, yet several barriers hinder the mobilization of these essential funds. The region faces significant infrastructure costs that are exacerbated by limited fiscal capacity among many governments. This creates a major hurdle for financing energy projects, as the initial capital required is often prohibitively high, particularly for renewable energy technologies (RETs) which have substantial upfront costs but lower operating expenses over time[98], [99].

Engaging the private sector through tested models such as public-private-partnership models is crucial for overcoming funding challenges; not forgetting, inconsistent policies, weak governance, and political instability create an unwelcoming environment for potential investors. Regulatory deficiencies and unclear obligations regarding renewable energy purchases often complicate the landscape, deterring private capital from entering the market[100], [101]. In addition, the perception of high risk associated with investments in SSA contributes to this issue, as many investors prefer to allocate resources to more stable markets[102].

International donors and development finance institutions play a significant role in bridging the investment gap. For instance, the Sustainable Energy Fund for Africa, created in 2011 and overseen by the African Development Bank (AfDB), supports private sector investment in renewable energy and energy efficiency. By offering technical assistance along with concessional and catalytic financing tools, the fund works to mitigate investment risks in areas such as green baseload power, green mini-grids, and energy efficiency initiatives[95].

SSA stands at a critical juncture where strategic investments can drive universal access to reliable electricity, unlocking economic potential and improving the quality of life for millions. Realizing this ambition requires bold action, sustained commitment, and effective collaboration among governments, private sector actors, and international partners. A comprehensive profile of the 10 selected cities covering population statistics, electricity access rates, main grid operators, critical challenges, regulatory frameworks, and priority intervention areas is provided in **Annex 1**.

4.0 Urban Population Growth Forecasts for 2030 and 2050 with Pathways to Achieving 100% Electricity Access

4.1 Population Growth Projections

This study adopts an estimation forecast methodology to project population growth for the 10 selected cities, as existing city-level population forecasts were unavailable in widely recognized global databases such as the United Nations (UN) and the World Bank. While these sources provide valuable national-level projections, they lack the granularity required for city-specific analyses, which is the primary focus of this research.

To address this gap, historical population data from the selected cities (**refer to Figure 4 in Chapter 2**) was analysed, and the Compound Annual Growth Rate (CAGR) was calculated using **Equations 1**. This approach enabled the development of population projections for the years 2030 and 2050. The dataset used for this analysis spans the period from 2000 to 2024, providing a robust foundation for understanding past demographic trends and extrapolating future growth patterns. By leveraging this detailed historical data, the study ensures that the projections are grounded in empirical evidence, offering a reliable basis for planning and policy development.

$$\boldsymbol{CAGR = \left(\frac{Ending\ value}{Beginning\ value}\right)^{\frac{1}{n}} - 1 - - - - - - - - - (1)}$$

Where:

- Beginning Value: Population in the base year (2000 for this analysis).
- Ending Value: Population of the latest year (2024 for this analysis).
- n: Number of years (2024 - 2000 = 24 years)

The analysis explores two distinct scenarios to project urban population growth under varying socio-economic and policy conditions:

Baseline Constant Scenario (BS)
This scenario assumes that the current CAGR for each city remains unchanged. It represents a continuation of historical growth trends without significant external influences or disruptions, providing a reference point for comparison with another scenario.

Accelerated Growth Scenario (AS)
The Accelerated Growth Scenario (AS) projects a 20% rise in the current CAGR. The region is undergoing rapid population expansion, with projections from other studies suggesting a doubling by 2050[103]. This surge is fuelled by high fertility rates, reduced mortality, and substantial rural-to-urban migration. Urban areas are growing as people move in search of better job prospects, healthcare, and improved living standards. However, this swift urbanization often outpaces the development of infrastructure and public services, resulting in issues like insufficient housing, overburdened utilities, and widening socio-economic gaps. By incorporating a 20% growth rate in

this scenario, these dynamics are accounted for. This rate captures the expected acceleration in population growth driven by the aforementioned factors, while avoiding overestimation of their potential effects. It offers a balanced approach for planning and policy formulation, ensuring readiness for future demographic changes.

Table 5:Selected Cities Population Rates for Baseline and Accelerated Growth (Source: MicroEnergy International Estimates - 2025)

City	2024 Population (millions)	BS (CAGR for 2000 -2024)	AS (Current CAGR +20%)
Lagos, Nigeria	16.54	3.26%	3.91%
Addis Ababa, Ethiopia	5.70	3.64%	4.37%
Abidjan, Côte d'Ivoire	5.86	2.97%	3.56%
Kigali, Rwanda	1,29	4.08%	4.90%
Johannesburg, South Africa	6.32	2.64%	3.17%
Kinshasa, DRC	17.03	4.06%	4.87%
Nairobi, Kenya	5.54	3.67%	4.40%
Dar es Salaam, Tanzania	8.16	4.47%	5.36%
Maputo, Mozambique	1,19	0.64%	0.77%
Lusaka, Zambia	3.32	4.72%	5.66%

As shown in **Table 5**, the Constant Baseline Scenario show that the 10 selected cities are experiencing an average CAGR of 3.41%, which is in line with the African Union's estimate of 3.5%[103],[104]. Among these cities, Dar es Salaam in Tanzania is witnessing the highest growth, while Maputo in Mozambique is growing at the slowest pace.

The CAGR from the two scenarios (Baseline Constant and Accelerated Growth), were applied to project the population of the 10 selected cities for the years 2030 and 2050. These forecasts were calculated using **Equation 2**, which provides a mathematical framework for projecting future population sizes based on annual growth rates. By employing this approach, the analysis captures potential variations in urban growth trajectories under different conditions, offering insights into the demographic trends that could shape these cities over the coming decades.

$$\boldsymbol{Future\ value = Present\ value * (1 + CAGR)^{n}} - - - - - - - - - - (\mathbf{2})$$

Where:

- Present Value: Population of the latest year (2024 for this analysis)
- Future Value: Projected population for the target years (2030 and 2050).
- n: Number of years from the present year (e.g., 6 years for 2030 and 26 years for 2050).

Table 6 presents population forecasts for the 10 selected cities for the years 2030 and 2050 across two scenarios, using the 2024 population figures as the baseline and applying the CAGR rates outlined in **Table 5**.

Table 6: Projected population for Selected Cities in 2030 and 2050 (Source: MicroEnergy International Estimates - 2025)

City		BS		AS	
	2024 population (Millions)	**2030 Projection (Millions)**	**2050 Projection (Millions)**	**2030 Projection (Millions)**	**2050 Projection (Millions)**
Lagos, Nigeria	16.54	20.05	38.09	20.82	44.86
Addis Ababa, Ethiopia	5.7	7.06	14.44	7.37	17.32
Abidjan, Côte d'Ivoire	5.86	6.98	12.54	7.23	14.57
Kigali, Rwanda	1.29	1.64	3.65	1.72	4.47
Johannesburg, South Africa	6.32	7.39	12.44	7.62	14.22
Kinshasa, DRC	17.03	21.62	47.93	22.66	58.66
Nairobi, Kenya	5.54	6.88	14.14	7.17	16.99
Der es Salaam, Tanzania	8.16	10.61	25.44	11.16	31.75
Maputo, Mozambique	1.19	1.24	1.40	1.25	1.45
Lusaka, Zambia	3.32	4.38	11.01	4.62	13.91

Lagos and Kinshasa, the two largest cities in SSA, are expected to remain the region’s primary population centres. In the baseline scenario, Lagos is projected to reach 20 million by 2030 and 38 million by 2050, aligning with Statista's estimate of approximately 24 million by [105]. Kinshasa's population could surpass 45 million by 2050, reinforcing its status as a rapidly expanding megacity. These urban giants will continue to shape economic and social dynamics across the region. Likewise, secondary cities such as Dar es Salaam and Lusaka are experiencing significant growth, with their populations anticipated to more than double by 2050, highlighting their increasing economic influence and emergence as key urban centres.

In contrast, established cities such as Johannesburg and Abidjan are experiencing slower growth but will still see substantial population increases, reinforcing their roles as key metropolitan areas. Meanwhile, smaller cities like Kigali, with a growth rate exceeding 4%, are emerging as vital urban centres. Kigali’s population is projected to more than double by 2050, driven by its strategic location and expanding economic influence.

4.2 Projected Electricity Access Rates

To achieve universal electricity access by 2030, Sub-Saharan Africa (SSA) needs to connect 110 million people annually, a target that is currently not being met. By analysing unmet demand, population growth rates, and electricity access rates by country, it is possible to estimate future access rates in the urban and peri-urban areas of the 10 selected cities. To determine future access rates, a hybrid approach with scenario analysis has been used. The baseline was established by analysing electricity access trends over the past 10 years or more, depending on availability of data. Like population growth projections, the CAGR formula (as described in **Equation 1** above) will be applied to calculate three different scenarios.

Where:

- Beginning Value: Electricity access rate in the base year (which differs in each city based on available data).
- Ending Value: Electricity access rate of the latest year (which differs in each city based on available data).
- n: Number of years between the base and ending year (i.e., 2024 - 2011 = 13 years)
- Assumption: 2024 has been used as the last year when data is available based on ending value.

Baseline Constant Scenario (BS)
This scenario is based on the most recent available data, assuming that each city's current CAGR remains constant over time. It represents a "business-as-usual" pathway, reflecting historical growth patterns and existing policy measures.

Accelerated Growth Scenario 1 (AS-1)
This scenario projects a 20% increase in the current CAGR, spurred by enhanced investments from electricity utility companies, reduced connection costs for both households and businesses, and rising demand linked to economic development.

Accelerated Growth Scenario 2 (AS-2)
This scenario anticipates a 100% increase in the current CAGR, driven by bold government initiatives aimed at universal access, large-scale renewable energy projects, and the adoption of advanced technologies such as off-grid solar systems and microgrids. **Table 7** outlines the projected electricity access rates for each of the three scenarios.

Table 7: Projected Electricity Access Rates for Selected Cities in 2030 and 2050 (Source: MicroEnergy International Estimates - 2025)

City	Start Year	Start year access Rate	Latest year with available data	Latest Year access rate	BS (CAGR for ~10 years)	AS-1 (Current CAGR +20%)	AS-2 (Current CAGR - 100%)
Lagos, Nigeria	2011	55.9%	2020	96%	6.19%	7.43%	12.39%
Addis Ababa, Ethiopia	2011	85.2%	2020	99.9%	1.78%	2.14%	3.57%
Abidjan, Côte	2011	92.0%	2021	94%	0.22%	0.26%	0.43%

d'Ivoire							
Kigali, Rwanda	2011	46.0%	2022	91.30%	6.43%	7.72%	12.86%
Johannesburg, South Africa	2011	90.4%	2022	94.10%	0.37%	0.44%	0.73%
Kinshasa, DRC	2011	44.0%	2020	60%	3.51%	4.21%	7.01%
Nairobi, Kenya	2009	72.4%	2019	96.70%	2.94%	3.52%	5.87%
Dar es Salaam, Tanzania	2011	42.9%	2022	87.0%	6.64%	7.97%	13.28%
Maputo, Mozambique	2011	68.0%	2019	96.5%	4.47%	5.37%	8.95%
Lusaka, Zambia	2011	48%	2022	96.6%	6.56%	7.88%	13.13%

Note: The 100% electrification rate is theoretical, as practical challenges may prevent absolute coverage.

As shown in **Table 7**, the Constant Baseline Scenario indicates that the 10 selected cities have an average current access rate of 92.1%, with an average electricity CAGR of 3.91%, compared to a population growth rate of 3.41%. This indicates the possibility of reaching 100% electrification by 2030. However, in some cities, the electricity access growth rate is slower than the population growth rate, and when combined with other challenges discussed in **Section 3.2**, achieving 100% connectivity may be difficult.

To project the timeframe required to achieve theoretical 100% electrification while accounting for both electricity access expansion and population growth, the CAGR method was applied across three scenarios: Baseline Constant Scenario, Accelerated Growth Scenario 1, and Accelerated Growth Scenario 2. An exponential growth formula was utilized for both population and electricity access to estimate the year in which theoretical full electrification would be attained.

- A result of zero years means electricity access has already reached 100%.
- A negative value indicates that, at the current growth rate, 100% electrification will never be achieved.
- A positive value represents the number of years required to reach 100% electrification.

The general formula for growth is shown in **equation 3** below:

$$\boldsymbol{A_t = A_0 * (1 + r)^t} \text{ --------------------------- } \mathbf{(3)}$$

where:

- A_0= Initial access rate
- r = electricity access growth rate
- A_t=target access rate
- t = number of years

The above formula calculates the number of years needed to reach 100% electrification assuming a constant population.

The results were adjusted with population growth rate using the below formulae.

$$\boldsymbol{\frac{A_0 * (1 + CAGR)^t}{(1 + population\ Growth)^t}} \text{ ----------------- } \mathbf{(4)}$$

Solving for t

$$t = \frac{In(100\%/A_O)}{(In((1+CAGR)/(1+Population\ Growth))/p)} ---------------(5)$$

Where:

- P= multiplier representative of additional factors affecting electricity access.

Table 8 provides projections for achieving 100% electrification in ten major African cities under a **Baseline Scenario**, which assumes a constant CAGR for both population growth and electricity access, based on historical trends.

Table 8: Baseline Scenario Projections for Population Growth and Electricity Access (Source: MicroEnergy International Estimates - 2025)

City	Number of years to reach 100% electrification for a constant growth in both access rate and population	Year Projected to reach 100% Electrification
Lagos, Nigeria	2.92	2027
Addis Ababa, Ethiopia	-0.11	Not Achievable
Abidjan, Côte d'Ivoire	-4.56	Not Achievable
Kigali, Rwanda	8.15	2032
Johannesburg, South Africa	-5.43	Not Achievable
Kinshasa, DRC	-191.47	Not Achievable
Nairobi, Kenya	-9.45	Not Achievable
Dar es Salaam, Tanzania	13.56	2038
Maputo, Mozambique	1.91	2026
Lusaka, Zambia	3.96	2028

Note: The 100% electrification rate is theoretical, as practical challenges may prevent absolute coverage

The analysis indicates that only five cities Lagos, Kigali, Dar es Salaam, Maputo, and Lusaka are projected to achieve theoretical full electrification if current population growth and electricity access rate remain consistent. Specifically, Maputo is expected to reach theoretical 100% electrification by 2026, followed by Lagos in 2027, Lusaka in 2028, Kigali in 2032, and Dar es Salaam in 2038. These cities benefit from relatively stable population growth rates and strong progress in electricity access expansion.

Conversely, the projections reveal significant challenges for cities like Addis Ababa, Abidjan, Johannesburg, Kinshasa, and Nairobi, which are marked as "Not Achievable" due to population growth rates outpacing electricity access expansion. Kinshasa, in particular, is projected to require over 191 years under the current trajectory, an indicator of the substantial gap between demand and supply. It is important to note that the 100% electrification target is theoretical, as practical challenges such as infrastructure limitations, policy barriers, and economic constraints may hinder absolute coverage.

Table 9 illustrates the estimated timelines for reaching theoretical 100% electrification under **Accelerated Growth Scenario 1**, which assumes a **20% Accelerated CAGR** for both population growth and electricity access.

Table 9:Accelerated Growth Scenario 1 Projections for Population Growth and Electricity Access (Source: MicroEnergy International Estimates - 2025)

City	Number of years to reach 100% electrification for an accelerated growth in both access rate and population	Year Projected to reach 100% Electrification
Lagos, Nigeria	2.45	2026
Addis Ababa, Ethiopia	-0.09	Not Achievable
Abidjan, Côte d'Ivoire	-3.81	Not Achievable
Kigali, Rwanda	6.86	2031
Johannesburg, South Africa	-4.54	Not Achievable
Kinshasa, DRC	-160.72	Not Achievable
Nairobi, Kenya	-7.93	Not Achievable
Dar es Salaam, Tanzania	11.42	2035
Maputo, Mozambique	1.60	2026
Lusaka, Zambia	3.34	2027

Note: The 100% electrification rate is theoretical, as practical challenges may prevent absolute coverage

Under this scenario, some cities show significant improvements in electrification timelines. Lagos, Kigali, Dar es Salaam, Maputo, and Lusaka benefit notably from the accelerated growth, with Dar es Salaam experiencing the most substantial reduction nearly two years in the projected time required to achieve universal electricity access. This suggests that enhanced growth rates can meaningfully impact electrification timelines in rapidly urbanizing regions.

However, several cities remain far from achieving universal access. Addis Ababa, Abidjan, Johannesburg, Kinshasa, and Nairobi are marked as "Not Achievable," indicating that even with a 20% CAGR, population growth continues to outpace electrification efforts, making 100% coverage impractical under current projections. Conversely, cities like Lagos (2026), Maputo (2026), and Lusaka (2027) are forecasted to reach full electrification within the next decade, while Kigali and Dar es Salaam are projected for 2031 and 2035 respectively. These projections highlight the critical need for targeted investments and infrastructure improvements to bridge the electrification gap, particularly in cities struggling with rapid urbanization.

Table 10 presents the projected timelines for achieving theoretical 100% electrification under **Accelerated Growth Scenario 2**, assuming an accelerated CAGR of 100% for both population growth and electricity access.

Table 10: Accelerated Growth Scenario 2 Projections for Population Growth and Electricity Access (Source: MicroEnergy International Estimates - 2025)

City	Number of years to reach 100% electrification for an accelerated growth in both access rate and population	Year Projected to reach 100% Electrification
Lagos, Nigeria	1.04	2025
Addis Ababa, Ethiopia	-0.39	Not Achievable
Abidjan, Côte d'Ivoire	-6.04	Not Achievable
Kigali, Rwanda	3.73	2028

Johannesburg, South Africa	-5.09	Not Achievable
Kinshasa, DRC	50.56	2075
Nairobi, Kenya	4.80	2029
Dar es Salaam, Tanzania	3.85	2028
Maputo, Mozambique	0.91	Not Achievable
Lusaka, Zambia	1.01	2025

Note: The 100% electrification rate is theoretical, as practical challenges may prevent absolute coverage

Under this scenario, cities such as Addis Ababa, Abidjan, Johannesburg, and Maputo are classified as "Not Achievable" due to population growth rates that outpace electrification efforts. Kinshasa faces the most substantial hurdle, requiring 50.56 years to reach theoretical 100% electrification, with its target extending to 2075. In contrast, Lagos and Lusaka are still anticipated to achieve full electrification by 2025, while Kigali and Dar es Salaam are projected for 2028 and Nairobi for 2029.

This analysis underscores the need for targeted investments to accelerate electrification, particularly in rapidly growing cities. Notably, only 7 out of the 10 cities are expected to reach theoretical universal access within the next 50 years. A demand-driven study by Castellano, Kendall, and Nikomarov (2015) estimated that by 2040, electricity demand in Sub-Saharan Africa would quadruple, yet electrification rates would only reach 70–80%, falling short of the Sustainable Development Goal (SDG) for 2030. For instance, the Multi-Tier Framework (MTF) Energy Access Household Survey of 2017 reported that Addis Ababa had a 99.9% electricity access rate, reflecting substantial investments in infrastructure. However, achieving absolute 100% access will necessitate continuous investments, infrastructure enhancements, and grid expansion to keep pace with demographic growth.

5.0 Key Considerations for Electrification and Potential Solutions

Electrifying urban and peri-urban areas in SSA presents a significant set of challenges but also provides a unique opportunity for transformative change. With rapid urbanization, population growth, and an increasing demand for energy, addressing the barriers to electricity access is crucial for economic growth and social development. This section highlights key considerations and potential solutions to overcome these challenges, focusing on innovative approaches, urban planning, and successful case studies from the region.

5.1. Key Considerations for Electrification

Infrastructure Deficits

A significant obstacle in the electrification of urban and peri-urban areas in SSA is the extensive deficit in infrastructure. Many cities such as Lagos, Kinshasa, especially in informal settlements, remain disconnected from the national grid or are served by outdated and underdeveloped grid systems. Aging infrastructure, compounded by insufficient investment in transmission and distribution networks, results in inefficiency, limited-service coverage, and unreliable electricity supply.

To address these challenges, a dual approach is necessary: strengthening the existing grid infrastructure while also exploring alternative solutions like decentralized energy systems. Governments and utilities should prioritize upgrading and expanding grid infrastructure, focusing especially on the most underserved regions. In parallel, decentralized energy solutions, such as mini-grids, solar home systems (SHS), and other renewable technologies, should be promoted to provide a reliable supplementary capacity where grid connections are either too costly or infeasible. Mini-grids are particularly effective in peri-urban areas and off-grid regions, offering affordable, scalable, and flexible solutions that can complement national grid efforts.

Affordability

The high cost of accessing electricity remains a key barrier in most cities in SSA, with costly connection fees and electricity charges serving as significant barriers. For most of the population, especially in urban and peri-urban settings where low-income households predominate, these costs are unaffordable.

To improve affordability, governments and utilities should implement targeted financial strategies, such as subsidies to reduce connection charges. Additionally, innovative financing models like energy-as-a-service can be vital in enhancing affordability. These models allow consumers to pay for electricity in small, manageable instalments, often using mobile money platforms, which is a practical solution due to the widespread use of mobile phones in SSA. Utilities can also consider progressive tariff structures that make electricity more affordable for low-income households while maintaining the financial viability of energy providers or additionally the bundling of electricity with electric devices supply.

Reliability and Quality of Supply

Almost all the 10 selected cities in this study experience frequent power outages, unreliable electricity supply, and voltage fluctuations, which undermine the quality of service and discourage further investment in grid connections. Poor-quality supply is a key issue that impacts both household energy usage and businesses that depend on consistent power.

To improve the reliability and quality of the electricity supply, substantial investment is needed in modernizing grid infrastructure. This includes integrating energy storage systems that can store excess energy generated during off-peak hours and discharge it during periods of peak demand. Additionally, the development of smart grids is essential. Smart grids employ advanced data analytics, communication technologies, and real-time monitoring to optimize energy distribution, reducing inefficiencies and improving service reliability. Moreover, increasing the share of renewable energy sources, such as solar and wind, can enhance grid stability by diversifying the energy mix and providing more reliable, sustainable power.

Policy and Regulatory Barriers
In most SSA cities, weak or inconsistent energy policies and regulatory frameworks hinder the growth of the energy sector. Bureaucratic inefficiencies, unclear regulations, and a lack of incentives for private sector involvement discourage investment in the energy infrastructure needed to accelerate electrification.

To unlock the potential for electrification, it is crucial to develop and enforce coherent, consistent, and transparent policies that encourage both local and international private sector investment. Governments should simplify approval processes for new energy projects and provide clear regulatory guidelines that facilitate renewable energy integration. Furthermore, offering targeted incentives, such as tax rebates, financial incentives, or subsidies for renewable energy projects, can help stimulate private sector participation. Streamlining regulatory frameworks will not only encourage investment but also foster innovation, driving the development of cost-effective, renewable energy solutions that are critical for scaling electrification efforts across SSA cities.

Environmental and Social Impacts
Expanding electricity access in SSA cities presents both environmental and social challenges. If not carefully managed, large-scale electrification can contribute to environmental harm, including deforestation, increased carbon emissions, and ecosystem disruption. Moreover, many energy projects overlook social equity, often failing to provide affordable and sustainable energy solutions to marginalized communities, such as low-income households and women. In cases like the Makoko floating slum in Lagos, lack of inclusive policies has resulted in energy access disparities, exacerbating existing inequalities rather than reducing them.

To address these challenges, prioritizing renewable energy sources such as solar, wind, and hydropower offers a sustainable alternative to fossil fuels, helping to minimize the environmental footprint of electrification. Additionally, energy projects should be designed with inclusivity in mind to ensure that underserved populations benefit. Community-driven initiatives, such as solar-powered mini-grids, can empower residents, create economic opportunities, and enhance capacity-building efforts. Engaging communities in decision-making and supporting income-generating activities can foster social equity and contribute to long-term development. Furthermore, targeted strategies should be implemented to address the specific energy access barriers faced by women, ensuring that electrification efforts promote gender-inclusive solutions.

5.2. Role of Urban Planning

Urban planning plays a critical role in expanding energy access and ensuring that electrification keeps pace with rapid urban growth, infrastructure development, and economic transformation across Sub-Saharan Africa (SSA). Effective planning can help prevent energy shortages, enhance grid resilience, and optimize resource allocation, particularly in the face of accelerating urbanization. As cities in SSA grow often faster than infrastructure can support many urban and peri-urban areas, especially informal settlements, struggle with inadequate energy access. These underserved zones often lack the infrastructure needed to accommodate dense populations, making energy distribution more complex.

To address these challenges, governments must adopt a holistic approach that embeds energy access within broader urban development strategies. This requires forward-looking planning that considers both current needs and future demand, with a focus on sustainable and inclusive energy solutions. Collaboration between urban planners and energy specialists can help ensure that energy infrastructure develops alongside urban growth, minimizing inefficiencies and ensuring fair electricity access for all urban communities. Key strategies include integrated energy planning, zoning regulations, resilient infrastructure design, and inclusive stakeholder engagement.

Integrated Energy and Urban Planning
To achieve sustainable and equitable electrification, urban planning should integrate energy infrastructure development with city expansion strategies. Many SSA cities are experiencing rapid population growth, often outpacing the expansion of electricity networks. By incorporating energy considerations into urban master plans, governments can ensure that infrastructure developments support both residential and commercial energy needs, avoiding energy bottlenecks and unsustainable informal grid connections. For example, Kigali has successfully integrated energy access with its urban development plans. The city's Master Plan 2050 includes provisions for electrification corridors, ensuring that new housing developments, industrial zones, and commercial hubs are planned alongside grid expansion projects[107]. This approach has led to higher electrification rates, minimized informal energy connections, and improved energy service delivery.

Zoning and Land Use Policies
Zoning regulations and land-use planning are critical for streamlining the deployment of energy infrastructure, particularly in informal settlements and peri-urban areas were land tenure issues often complicate electrification efforts. For example, in cities like Nairobi and Lagos, informal settlements are widespread, and land tenure is often unregulated, making it difficult to establish legal energy connections. In Nairobi, the Informal Settlements Improvement Project has focused on addressing land tenure and upgrading infrastructure, including energy access, by developing clear zoning regulations that integrate informal settlements into formal urban planning frameworks. This has allowed utilities to expand electricity networks more effectively while respecting the informal land use that exists[108].

This example clearly demonstrates how tailored land-use policies and zoning regulations have been used to improve energy access in informal settlements, ensuring that utilities, policymakers, and private investors can coordinate infrastructure expansion. Such frameworks help minimize conflicts related to land access and ownership, particularly in informal areas where residents lack formal land titles. Through collaborations with utility providers, policies have been designed to legalize energy connections while addressing land tenure complexities, ultimately reducing illegal grid connections and improving energy access in low-income communities across SSA cities.

Resilient Infrastructure Design

The rising frequency of extreme weather events, including floods, heatwaves, and storms, poses significant challenges to energy infrastructure across SSA. In cities like Dar es Salaam where flooding, heatwaves is a frequent issue due to rapid urbanization and climate change, climate-resilient urban planning is essential to protect the electricity supply. It is important to strengthen the grid infrastructure by investing in flood-resistant substations, underground power lines, and smart-grid technologies. These measures enhance grid reliability and reduce the risk of electricity disruptions caused by heavy rains and rising water levels. Additionally, by elevating transformers, using waterproof substations, and integrating climate-resilient grid components.

Inclusive Planning Processes

Electrification projects must reflect local needs and priorities, ensuring that energy solutions are affordable, reliable, and tailored to the needs of different communities. Participatory urban planning that involves local stakeholders, businesses, and community representatives can enhance public trust, reduce resistance to energy projects, and promote socially inclusive electrification strategies. For instance, in South Africa, community-driven energy planning has been instrumental in designing off-grid solar mini-grids for informal settlements. By incorporating local input on energy demand, pricing models, and service expectations, planners have ensured that electrification projects are socially and economically viable, increasing community buy-in and long-term sustainability[91].

5.3. Innovative Approaches

Innovation is a driving force in accelerating electrification in urban and peri-urban areas across SSA. Emerging technologies and business models are transforming the energy landscape by offering scalable, efficient, and cost-effective solutions tailored to the region's unique challenges. These innovations go beyond traditional electrification approaches by integrating smart grids, decentralized renewable energy systems, mobile energy storage, and digital financial models, ensuring greater accessibility and reliability. As technology progresses, these solutions continue to evolve, driving sustainable energy transformation.

Grid Solutions

Expanding electricity access in SSA requires innovative grid solutions that address distribution network challenges, minimize power losses, and enhance system resilience. Many SSA cities face significant grid infrastructure issues, including aging transmission and distribution networks, high levels of power theft, voltage fluctuations, and an inability to integrate distributed energy resources effectively. These innovations focus on hardware, software, and non-technical solutions tailored to the unique challenges of urban and peri-urban areas.

- **Smart Grid Technologies**

Smart grids play a crucial role in modernizing electricity distribution across SSA by enabling real-time monitoring, adaptive energy management, and greater resilience against climate-related disruptions. These advanced systems incorporate sensors, automation, and digital communication technologies to enhance efficiency, minimize outages, and support the integration of renewable energy sources such as solar and wind. Equipped with predictive demand algorithms and real-time load balancing, smart substations and transformers help stabilize voltage fluctuations and reduce grid instability, especially in cities with a high concentration of decentralized energy systems. In

Johannesburg, for instance, the deployment of smart substations has improved the management of distributed energy resources, mitigating the risks of power outages and network imbalances[109]. Furthermore, cloud-based analytics strengthens grid monitoring, curbs unauthorized energy access, and enhances overall system resilience. By integrating digital technologies into distribution networks, smart grids not only improve operational efficiency but also facilitate cost-effective and climate-resilient grid expansion.

- **Advance Metering Infrastructure (AMI)**

AMI are a critical tool for addressing grid challenges in SSA by providing real-time monitoring of energy consumption, improving billing accuracy, and reducing technical and commercial losses. In cities such as Lagos and Kinshasa, where outdated infrastructure and electricity fraud are prevalent, smart meters could enable utilities to detect power theft, optimize load distribution, and enhance revenue collection. By integrating cloud-based data analytics, utilities can further refine grid management strategies and predict consumption patterns for better service delivery.

- **Demand-Side Management**

Beyond metering, demand-side management strategies play a key role in optimizing electricity consumption and reducing peak demand. DSM initiatives include time-of-use pricing, consumer awareness programs, and load-shifting incentives, encouraging households and businesses to adjust their energy use to off-peak hours. These interventions help stabilize the grid, reduce reliance on expensive backup generation, and enhance overall energy efficiency. By leveraging insights from smart meter data, utilities can design targeted DSM programs that align with consumer behaviour and grid capacity.

- **Integration of Distributed Energy Resources (DERs)**

A critical challenge for grid expansion in SSA is the effective management and dispatch of Distributed Energy Resources (DERs), particularly solar photovoltaic (PV) systems. Many SSA cities are witnessing a rapid increase in decentralized energy generation, yet their grids often struggle to accommodate the variable supply from renewable sources. To address this, utilities should implement dispatch strategies, such as dynamic voltage regulation and decentralized energy coordination, to balance supply and demand efficiently. Energy providers should develop voltage control mechanisms to stabilize fluctuations caused by rising solar PV installations, ensuring grid reliability while supporting the transition to cleaner energy sources. By fostering public-private partnerships (PPPs) for DER management and dispatch, SSA can leverage private sector expertise and investment to enhance grid stability, optimize energy distribution, and accelerate the widespread adoption of distributed renewable energy solutions.

- **Hardware Advanced Solutions**

Upgrading physical infrastructure is fundamental to improving the reliability and capacity of power distribution networks, particularly in densely populated or informal urban areas. Hardware advanced solutions, such as high-efficiency transformers, insulated high-capacity cables, and compact modular substations, enable increased power throughput while reducing system losses and operational footprints. These technologies are especially critical in mitigating issues like overloaded transformers and bottlenecks exacerbated by illegal connections. Prioritized investments in infrastructure reinforcement, driven by localized demand and technical feasibility assessments, can significantly improve grid resilience. Phased implementation in high-demand zones ensures optimized resource allocation and quicker impact in underserved communities.

Off-Grid Solutions

While grid expansion efforts continue across SSA, millions of people still live in remote or underserved areas where extending the national grid is not economically viable. Off-grid solutions provide a critical alternative, delivering decentralized, reliable, and affordable electricity to rural and peri-urban communities. These solutions play a vital role in energy access, economic development, and resilience-building, particularly for businesses, schools, health centres, and households. Off-grid electrification primarily involves mini-grids, microgrids, solar home systems (SHS) and other off-grid solutions, each offering tailored benefits to different energy needs and contexts.

- **Mini-Grids and Micro-Grids**

Despite the presence of the main grid, some households and enterprises opt for off-grid systems like mini-grids and microgrids due to their reliability, affordability, and ability to support productive uses of energy. Informal settlements, industrial zones, and fast-growing urban outskirts often experience voltage fluctuations and limited grid coverage, making decentralized energy systems a viable solution for improving energy access and resilience.

While both mini-grids and micro-grids serve as decentralized energy solutions, they differ in terms of size, flexibility, and operational structure. Mini-grids are typically designed for rural and off-grid communities, ranging from several kilowatts (kW) to over 100 megawatts (MW) in capacity, and often function as standalone systems without direct integration into the national grid. In contrast, microgrids are usually deployed in peri-urban and urban areas, ranging from hundreds of kilowatts (kW) to tens of megawatts (MW), with the ability to seamlessly switch between grid-connected and islanded operation modes. Additionally, micro-grids often incorporate advanced control systems, real-time energy management, and demand-side response mechanisms, making them more adaptive to fluctuating electricity demand and grid conditions. The choice between a mini-grid or micro-grid depends on the specific energy needs, geographic location, and the level of existing grid infrastructure in each area.

Mini grids are localized electricity networks that generate, store, and distribute power independently from the national grid. These systems, typically powered by solar, wind, hydro, or biomass, provide a scalable and cost-effective solution for electrification in remote areas where grid extension is impractical. Mini grids are particularly beneficial for rural communities, agricultural processing units, small businesses, and public institutions such as schools and health centres. In Tanzania, the JUMEME Rural Power Supply project has successfully deployed solar-hybrid mini-grids in remote fishing villages along Lake Victoria, bringing electricity to thousands of households and businesses[110]. By incorporating battery storage and diesel backup, these mini grids ensure uninterrupted power supply, enabling fishermen to refrigerate and process fish, thereby reducing post-harvest losses. Additionally, mini grids play a crucial role in healthcare electrification by providing stable power to hospitals and rural clinics. Leveraging public-private partnerships (PPPs) and innovative financing models, mini-grids continue to expand, offering sustainable energy solutions to underserved populations across SSA.

Both micro-grids and mini grids, provide localized power generation but with the added flexibility of operating independently or in conjunction with the main grid. This hybrid capability makes them particularly valuable in cities like Kinshasa and Lagos, where frequent blackouts, voltage fluctuations, and unreliable grid supply disrupt daily activities. Micro-grids incorporate battery storage, smart energy management systems, and demand-side control mechanisms to optimize electricity generation and consumption. In Kenya, Strathmore University operates a solar-powered micro-grid that ensures energy reliability for students, faculty, and nearby businesses while feeding surplus power into the national grid[111]. Micro-grids are also vital for disaster resilience and humanitarian response. In Mozambique, following the devastation caused by Cyclone Idai, solar microgrids were rapidly deployed to power relief camps, water pumping stations, and emergency medical services[112]. These deployments underscore micro-grids' critical role in energy security, climate resilience, and disaster preparedness.

- **Solar Home Systems (SHS)**

For individual households, Solar Home Systems (SHS) provide an affordable, modular, and rapidly deployable off-grid solution. These systems typically include solar panels, battery storage, LED lights, and small appliances such as fans, radios, or televisions, offering a reliable alternative to kerosene lamps and diesel generators. The Pay-As-You-Go (PAYGO) financing model, further detailed in the Commercial solutions section, has been instrumental in expanding SHS adoption across SSA, allowing low-income households to pay in small instalments via mobile money rather than making high upfront investments. Companies such as M-KOPA (Kenya), ZOLA Electric (Tanzania), and Lumos Global (Nigeria) have successfully deployed PAYGO-based SHS, enabling millions of families to access clean and affordable electricity.

- **Innovative Business Models and Financing for Off-Grid Expansion**

Scaling up off-grid electrification requires innovative business models and financing mechanisms that attract private sector investment while ensuring affordability for consumers. Key approaches include:

  - Results-Based Financing (RBF): Provides incentives for private developers to expand off-grid solutions, as seen in the Beyond the Grid Fund for Africa (BGFA), which has supported mini-grid and SHS deployment in Zambia, Liberia, and Burkina Faso.
  - Blended Finance: Combines public and private sector investments to de-risk off-grid electrification projects. The AfDB’s Desert to Power Initiative is a prime example, leveraging concessional loans and grants to drive solar expansion in the Sahel region.
  - Carbon Credit Schemes: Off-grid solar companies, such as Bboxx generate revenue by selling carbon credits earned from replacing kerosene lighting with clean energy solutions.
  - Productive Use of Energy (PUE) Models: Encourage income-generating activities such as solar-powered irrigation, milling, and refrigeration, ensuring that off-grid solutions support economic growth.
  - Microcredit and Peer-to-Peer Lending: Small-scale financing through microcredit programs enables low-income households and small businesses to afford off-grid solar solutions. Peer-to-peer (P2P) lending platforms connect investors directly with off-grid entrepreneurs, facilitating flexible and accessible financing for clean energy adoption.
  - Crowdfunding for Off-Grid Projects: Digital crowdfunding platforms allow individuals and institutions to invest in renewable energy projects. Initiatives like Trine and Sun Funder have successfully mobilized capital from global investors to finance mini-grids and SHS deployments in underserved regions.

Energy Storage Based Solutions

Expanding energy access and ensuring grid stability in SSA requires innovative energy storage solutions to mitigate the intermittency of renewable energy sources such as solar and wind. Energy storage technologies, including lithium-ion batteries, pumped hydro storage, and emerging technologies such as vehicle-to-Grid (V2G), play a crucial role in enhancing grid reliability, reducing dependence on fossil-fuel backup systems, and enabling a more sustainable energy transition. In rapidly growing urban centres such as Dar es Salaam, Nairobi, Lagos, and Addis Ababa, scalable energy storage solutions will help address power fluctuations, support distributed energy resources, and improve overall electrification outcomes.

- **Battery Energy Storage Systems (BESS) for Grid Stability**

Battery Energy Storage Systems (BESS) are playing a crucial role in enhancing grid stability and providing backup power in SSA, particularly in cities that experience frequent blackouts and voltage fluctuations. Deploying large-scale lithium-ion batteries can facilitate the seamless integration of distributed solar photovoltaic (PV) systems. In metropolitan areas with high electricity demand from both residential and commercial consumers, battery storage can help alleviate grid congestion during peak hours. Additionally, repurposed EV batteries are emerging as a cost-effective storage solution, allowing surplus solar energy to be stored and utilized as needed. The declining cost of battery storage is also making decentralized mini-grid solutions more feasible, especially for peri-urban areas grappling with unreliable electricity access.

- **Pumped Hydro Storage and Large-Scale Energy Reserves**

In addition to battery storage, pumped hydro storage stands as one of the most efficient large-scale energy storage solutions in Sub-Saharan Africa. In Kenya, the Seven Forks Dam is undergoing evaluation for the integration of pumped hydro storage to capture excess renewable energy and enhance national grid stability[113]. The project seeks to utilize surplus solar and wind energy to pump water into elevated reservoirs, which can then be released to generate hydroelectric power during peak demand periods. This approach boosts energy security while minimizing reliance on fossil-fuel-based Peaker plants. Similarly, Ethiopia, with its abundant hydroelectric resources, is investigating the potential for hybrid hydro-solar storage systems. The Grand Ethiopian Renaissance Dam (GERD) offers an opportunity to supplement solar and wind power with stored hydroelectric energy, ensuring a consistent and dependable electricity supply[114]. The combination of diverse storage technologies will help cities like Addis Ababa expand electrification while minimizing grid vulnerabilities. However, given that these solutions are part of long-term national strategies and require significant capital investment, they fall outside the scope of this study, which focuses on projects with a more localized impact.

- **Vehicle-to-Grid (V2G) Technology**

V2G enables electric vehicles (EVs) to act as energy storage units, feeding power back into the grid during peak demand and recharging when demand is low. This technology enhances grid stability, optimizes renewable energy use, and reduces reliance on costly diesel generators. Additionally, V2G creates new revenue streams for EV owners by enabling participation in demand response programs. SSA cities experiencing frequent power shortages such as Nairobi and Dar es Salaam should explore V2G integration, particularly in electric buses and taxis. These fleets can store surplus solar and wind power during the day and discharge it during evening peak demand, reducing grid stress and improving overall energy reliability.

- **Mobile Energy Storage Solutions**

Beyond V2G, mobile energy storage systems including modular battery units and battery swapping technology offer additional opportunities to enhance energy access and resilience. Battery swapping stations can improve the efficiency of electric public transport fleets by minimizing downtime associated with charging. Meanwhile, transportable modular battery units can provide reliable, on-demand energy storage in off-grid areas. These units can support micro-businesses, irrigation systems, and health clinics while enhancing resilience in disaster-prone regions by maintaining essential services during power outages. Additionally, they can be deployed at the household level, allowing families in remote areas to store renewable energy for use during periods of low generation or grid outages, ultimately reducing reliance on expensive and polluting backup generators.

End Uses Solutions

Beyond household electrification, expanding electricity access for productive and public-use applications is crucial for economic development, security, and overall urban sustainability. Innovative solutions for end-users in SSA cities can transform how electricity is consumed, managed, and leveraged to improve livelihoods. These solutions focus on increasing energy efficiency, optimizing power use, and integrating smart technologies to enhance service delivery and affordability.

- **Smart Street Lighting**

Smart street lighting is a game-changing innovation that integrates energy-efficient LED lights with motion sensors, adaptive controls, and solar-powered systems to improve urban safety and optimize energy consumption. In SSA cities like Lagos, Kinshasa and Nairobi, inadequate street lighting has contributed to security concerns, limiting business hours and increasing crime rates. The installation of solar-powered smart streetlights in informal settlements and commercial districts can reduce crime in some areas, allowing businesses to operate longer into the night. These systems automatically adjust brightness based on pedestrian and vehicle traffic, reducing electricity costs while enhancing public safety. Additionally, smart streetlights can be integrated into the city's broader smart city infrastructure, collecting valuable data on air quality, traffic patterns, and public movement, which city planners can use to enhance urban mobility.

- **Energy-Efficient Appliances and Devices**

Promoting the adoption of energy-efficient appliances is crucial in SSA cities where grid reliability is a challenge, and electricity costs are high. Innovations in smart appliances, efficient lighting, and cooling technologies ensure that electrification efforts lead to sustainable and cost-effective energy use. In Cities such as Lagos, where power outages are frequent, households and businesses can adopt smart refrigerators and LED lighting to reduce energy consumption. Similarly, efficient solar water heaters, efficient e-cooking with induction cooker or microwaves ovens, can reduce reliance on firewood and charcoal for heating, improving household energy security and reducing indoor air pollution.

Commercial Solutions

In SSA, the challenge of ensuring reliable electricity access for low-income communities can be effectively tackled through innovative commercial models that enhance the affordability and accessibility of energy. Solutions such as Energy-as-a-Service (EaaS), and community solar programs are flexible and cost-efficient alternatives for electrification. However, the successful deployment and expansion of these models depend on the establishment of strong regulatory frameworks. Effective regulations are essential to ensure the smooth operation of these models, facilitate market growth, protect consumers, and attract investment in energy infrastructure.

- **Energy-as-a-Service (EaaS) and PAYGO Model**

Energy-as-a-Service (EaaS) is revolutionizing the way electricity is delivered and consumed, particularly in areas with informal or unstable households. A key innovation within the EaaS framework is the Pay-As-You-Go (PAYGO) model, which enables consumers to pay for electricity based on their usage, often through mobile money platforms. This approach is particularly beneficial for underserved populations who may not have access to traditional banking or financing options. PAYGO allows consumers to purchase energy in small, affordable increments, providing them with flexibility and control over their energy consumption.

One example of EaaS in action is a "camping-like" electrification model that aligns with the principles of PAYGO. In peri-urban areas with high levels of mobility and turnover, a local distribution company could install power columns equipped with pay-per-use plugs. These plugs enable consumers to connect to a low-voltage network via short, aerial cables (ranging from 10 to 100 meters), offering on-demand electricity access. PAYGO model eliminates the need for expensive infrastructure investments and making energy more affordable.

This solution is ideal for areas with fluctuating energy demands or high population turnover, such as informal settlements or cities like Lagos and Kinshasa, where traditional grid-based electrification may not be financially viable. The mobile, low-voltage connections can be easily relocated as needed, providing an adaptable and scalable solution. Additionally, by shifting the financial burden from consumers to service providers, this model promotes greater energy accessibility while encouraging renewable energy adoption and reducing reliance on fossil fuels.

- **Community Solar Programs**

Community Solar Programs provide a scalable and cost-effective alternative for households, businesses, and institutions that may not have access to standalone solar home systems (SHS). These programs allow multiple participants to benefit from a shared solar energy system without the need for individual rooftop installations. A shared ownership or subscription model enables participants to either buy shares in the system or subscribe to receive electricity, reducing upfront investment costs. Community solar projects can be grid-connected or off-grid, feeding excess energy into the national grid to lower electricity costs or operating independently in remote areas.

In Ethiopia, the Solar Village Initiative has successfully piloted community-based solar hubs, where households collectively contribute to maintenance and operation, ensuring long-term sustainability[115]. These models are particularly effective in informal settlements, refugee camps, and rural villages, where shared ownership reduces financial burdens and enhances energy access. Beyond off-grid solutions, on-grid community solar models complement existing infrastructure by integrating decentralized solar generation with local distribution networks. This hybrid approach improves grid reliability, promotes energy equity, and facilitates broader clean energy adoption in peri-urban and rural areas.

- **Delegated management models**

Delegated power distribution involves transferring electricity distribution responsibilities from a national utility to private firms within specific areas. Under this model, private distributors purchase electricity at discounted rates and resell it to consumers while managing metering, infrastructure, and service delivery. This model allows private entities and organized groups to enhance electricity access in underserved settlements. This model aims to improve service efficiency, reduce power theft, and ensure safer electricity connections in high-density informal settlements where illegal connections are prevalent. The benefits of this model include improved service reliability, expanded infrastructure investment (the redistributors are mandated to construct new distribution lines), and adherence to regulated tariffs and network standards[116].

5.4. Case Studies

Lusaka, Zambia, and Dar es Salaam, Tanzania, were selected as case study locations due to their impressive strides in electricity access over the past decade. Lusaka's access rate surged from 48% in 2011 to 96.6% in 2022, reflecting a Compound Annual Growth Rate (CAGR) of 6.56%. Similarly, Dar es Salaam witnessed a notable increase from 42.9% to 87% during the same period, with a slightly higher CAGR of 6.64%. Despite these significant advancements, further efforts are required to achieve universal access.

Box 3

Lusaka's Electrification Journey: Progress and Challenges

Lusaka's electrification journey has been a transformative effort aimed at improving the socio-economic well-being of its residents. The process has evolved over decades, shaped by policy reforms, infrastructure development, and a recognition of the vital role electricity plays in reducing poverty and driving economic growth.

Policy and Institutional Framework

The foundation of Zambia's electrification efforts was laid with Zambia adopting the Poverty Reduction Strategy Paper (PRSP) in 2002, where the government identified electrification as a critical pillar for development. At the time, national electrification rates were alarmingly low, only 2% in rural areas and 20% overall. The government set ambitious electrification goals, targeting 15% coverage in rural areas and 50% in urban areas by 2010, with a long term objective of 51% rural and 90% urban electrification by 2030[117]. The journey gained momentum with the enactment of the Rural Electrification Authority (REA) in 2006 and the adoption of the Rural Electrification Master Plan (REMP) in 2007. While these initiatives primarily targeted rural areas, they also influenced urban electrification through grid extension projects. The Zambia National Energy Policy (NEP) of 2019 further emphasized universal access to improved energy, reinforcing the government's commitment to urban households.

Grid and off-grid solutions

Lusaka, has witnessed a remarkable transformation in electricity access, rising from 48% in 2011 to 96.6% in 2022, driven largely by proactive government initiatives focused on expanding the national grid and harnessing the country's solar energy capacity. As of 2017, under its National Energy Plan, the Zambian government committed to deploying 500,000 solar home systems and establishing at least 100 MW of utility-scale solar PV farms by 2030. These efforts were part of a broader strategy to diversify the national energy mix and ensure sustainable access to electricity. In Lusaka, these interventions have been critical in accelerating access rates and addressing urban energy demand. To encourage private sector participation, institutions like the Rural Electrification Authority (REA) and Energy Regulation Board (ERB) rolled out a range of financial incentives, including tax waivers on imported renewable energy equipment, and feed-in tariffs designed to attract investment in solar mini-grids and other decentralized solutions, which also serves peri urban areas[118].

Challenges to Electrification in Lusaka
Although progress has been substantial, urban electrification faces hurdles. High poverty levels (23.4% in the country urban areas) and steep connection fees ranging from $240 to $400 (as of 2017), plus wiring costs deter low-income households from accessing grid electricity. Additionally, unreliable power supply has prompted many households to adopt standalone solar systems as backup solutions, showcasing the need for grid stability.

While the policy focus on grid extension has proven effective, it has sometimes overlooked the potential of hybrid electrification approaches. Off-grid solutions, such as mini-grid solar PV systems, could complement urban electrification, especially in informal settlements or areas with sporadic grid access.

The Path Forward
Zambia's vision for 100% electrification in Lusaka is within reach but realizing it will require addressing affordability and reliability issues. Policymakers might consider subsidies for connection fees, targeted support for low-income households, and incentivizing private-sector participation in off-grid solutions. Enhancing grid infrastructure to minimize outages and adopting flexible tariff structures could further accelerate urban electrification.

Box 4

Dar es Salaam's Electrification Journey: Progress and Challenges in Urban Areas

Tanzania remains limited in access to electricity services. There is a significant disparity in electricity access rates in urban areas (99.6%) and rural areas (69.6%). Connectivity rates have increased in recent years, estimated to be 46% in 2022, however connection rates are still low with urban and rural areas standing at about 79%and 36%, respectively[119]. Dar es Salaam boasts an impressive electricity connectivity rate of 87%, while other urban areas average around 59% connectivity.

Policy and Institutional Framework
The National Energy Compact outlines ambitious targets, aiming to increase electricity connectivity to 75% by 2030 and strengthen the renewable share in the generation mix to 75% through public-private partnerships and policy reforms. Key institutions involved include: the Ministry of Energy (MoE), TANESCO (the state-owned utility), and the Energy and Water Utilities Regulatory Authority (EWURA). The Rural Energy Agency (REA) also plays a crucial role in expanding access to underserved areas, even in peri-urban regions.

Electricity access in Dar es Salaam

- **Grid Extension and Connectivity**

One of the strategies for increasing electricity access in Dar es Salaam has been the subsidized expansion of the central grid, led by TANESCO (Tanzania Electric Supply Company) and supported by the Rural Energy Agency (REA). The government, particularly between 2015 and 2021, prioritized electrification as a national goal, accelerating connections in peri-urban areas like Ilala. The REA program significantly reduced connection costs, allowing households to pay only VAT (18%) rather than the full infrastructure fee. This policy shift made electricity more accessible to low-income residents, leading to a rapid increase in connections. Additionally, political pressure ensured that electrification projects were fast-tracked, even in remote districts, demonstrating how state-led initiatives can drive infrastructure development.

- **Community and Neighbourhood Collaboration**

In areas where grid expansion was slow, community-driven strategies played a crucial role. Residents in peri-urban neighbourhoods like Msongola and Chanika organized collective efforts to share the cost of infrastructure, such as electricity pylons, making connections more affordable. Some communities also engaged in political mediation, lobbying local representatives and MPs to prioritize their areas for electrification. These bottom-up approaches highlight how local cooperation, and advocacy can complement government efforts, ensuring that even the most remote areas gain access to electricity.

Challenges facing electrification

As 2013, densification (the connection of new customers to the distribution network in already electrified settlements), was the most cost-effective method of connecting households when compared with other technologies but nevertheless this was still substantial; on average 747 US$ per new connection. In Dar Es Salaam, for example, only about 60% of households were connected at the end of 2013 and the percentage was significantly lower in the other electrified towns. The Tanzania electrification program prospectus estimated then that in the period 2013 – 2022, about 160,000 new customers will on average be connected annually in settlements already electrified by the end of 2021. However, the actual pace has significantly exceeded expectations , with the country currently averaging 500,000 new connections per year [119].

Despite advancements, and the growth in energy generation, and new transmission lines, Dar es Salaam experiences frequent power cuts due to aging infrastructure and increased demand. The distribution network struggles to maintain a stable electricity flow, which complicates efforts to ensure reliable service. These outages have frustrated residents and hindered business operations, with reports of power interruptions occurring multiple times daily. Upgrades are underway at key facilities like the Ubungo Power Station to address these issues, but temporary outages are expected during this process.

The Path Forward

To achieve its electrification goals, Tanzania will continue to focus on infrastructure upgrades, policy reforms, and increased private-sector participation. The government of Tanzania displays commitment to revising connection subsidy policies to improve affordability, scaling up distributed renewable energy solutions, and harmonizing regional interconnection frameworks to facilitate availability of power. Strengthening the financial viability of the national utility company, alongside targeted investments in grid stability and last-mile connections, will be key to sustaining progress and achieving universal energy access in urban areas by 2030.

6.0 Recommendation for further feasibility study for Selected Cities

6.1 Lagos, Nigeria

Lagos, Africa's most populous city, faces major electricity access issues due to an inadequate power supply, high demand, and significant commercial losses, including a 14% rate of electricity theft and widespread unmetered connections. Despite Nigeria having the infrastructure to generate up to 13 gigawatts (GW) of electricity, the outdated national grid can only distribute about one-third of this capacity. Consequently, Lagos receives less than 1,000 megawatts (MW) daily, which is far too little for its population of over 12 million. This limited supply results in an average of just 12 hours of electricity per day, forcing many to rely on backup generators, especially in informal settlements where grid access is unreliable or absent.

A study conducted by the Lagos State Electricity Board (LSEB) in 2014 estimated that the city maintains an off-grid generator capacity of approximately 15,000 MW, highlighting the vast energy deficit. In response to these challenges, Phase 2 of this study should incorporate feasibility studies focusing on solar powered mini-grids and micro-grid as well as advanced metering infrastructure (AMI).

6.1.1 Solar hybrid mini-grids and micro-grids

Rationale

Mini-grids and microgrids with battery storage offer an immediate and scalable solution to Lagos's electrification challenges by delivering decentralized, reliable power especially in residential zones that have developed outside formal urban planning and regulatory frameworks(e.g., Makoko, Ajegunle) and industrial clusters such as Apapa Port. These systems can operate independently or in tandem with the unreliable main grid, significantly reducing diesel dependence. With the enactment of Nigeria's Electricity Act 2023, which empowers private sector participation, mini grids have become a cost-effective and resilient pathway to electrification. Their levelized cost of electricity (LCOE) ranges from $0.18–$0.30/kWh, compared to diesel's $0.40/kWh. These systems can be rapidly deployed, offering not just improved energy access and reduced emissions, but also stimulating economic activity and supporting inclusive growth across Lagos.

Feasibility Study Areas

- **Optimal Site Identification**: Conduct geospatial analysis to prioritize high-demand zones (e.g., industrial clusters like Agbara/Ikeja and underserved settlements like Makoko) based on energy demand density, grid reliability gaps, and economic activity.
- **Sustainable Business Model**: Assess the profitability of private operators (e.g., Rensource, Husk Power) in deploying mini grids that serve both anchor tenants (factories) and residential consumers.
- **Grid Integration Strategy**: Evaluate whether mini grids should operate independently or be designed for future connection to the national grid.
- **Regulatory Framework**: Explore ways for Lagos State to streamline the permitting process for private mini-grid developers.

6.1.2 Advanced Metering Infrastructure (AMI)

Rationale

Lagos experiences high commercial losses including electricity theft and unmetered connections. The city's two electricity distribution companies (DisCos), Ikeja Electric and Eko Electric, face revenue collection challenges that hinder infrastructure investment. An AMI rollout could significantly enhance billing accuracy, reduce losses, and enable real-time electricity consumption monitoring.

Feasibility Study Areas

- **Technical Viability**: Identify the most cost-effective strategy for Advanced Metering Infrastructure (AMI) deployment whether through a full citywide rollout or a targeted approach in high-loss areas.
- **Financial Model**: Explore the potential of public-private partnerships (PPPs) with DisCos and technology providers (e.g., Schneider Electric, Huawei) to enhance the affordability of smart metering.
- **Consumer Adoption**: Assess the willingness of low-income households to adopt prepaid smart meters and the role of mobile money integration in improving payment compliance.
- **Regulatory Framework**: Evaluate necessary tariff adjustments or subsidies to balance cost recovery for DisCos while ensuring affordability for consumers.

6.1.3 Community Solar program

Rationale

Community solar programs offer a transformative solution for Lagos's urban and peri-urban areas, where space limitations, high costs, and other constraints make individual rooftop solar challenging. These programs enable shared ownership and subscription-based solar access, allowing residential estates, commercial hubs, and multi-family buildings to transition from passive consumers to prosumers, contributing clean energy to the grid. By overcoming space constraints, such as those in high-density areas like Victoria Island and Ikeja, shared solar systems maximize energy output, offering significant cost savings up to 50% cheaper than individual solar home systems or diesel generators. The programs also enhance grid resilience by feeding excess energy back into Lagos's grid and provide backup power during outages.

Feasibility Study Areas

- **Consumer Adoption**: Evaluate the willingness of residents and businesses to adopt community solar, focusing on affordability and payment methods like mobile money.
- **Regulatory Framework**: Analyse the regulatory landscape and identify necessary adjustments in tariffs, incentives, or policies to support community solar.
- **Financial Model**: Explore PPP opportunities and bulk procurement strategies to reduce costs and enhance affordability for participants.

6.2 Nairobi, Kenya

Nairobi, Kenya's capital, struggles with reliable electricity access in informal settlements due to widespread illegal connections. These overloaded transformers, cause outages, and limit the utility's capacity for legal connections. High connection costs and poverty drive residents toward unauthorized tapping, increasing technical losses and fire risks. The dense, unplanned nature of these areas further complicates grid expansion and maintenance. To address these challenges, four targeted interventions are proposed to improve legal access, reduce technical losses, enhance safety, and streamline grid extension efforts, aiming to stabilize electricity supply and support sustainable urban development.

6.2.1 Delegated Management Models

Rationale
Collaborating with community-based organizations (CBOs) and private entities to manage electricity distribution in informal settlements can improve service delivery and reduce illegal connections. For instance, by investing in underground cabling the risks associated with vandalism and theft, wayleave challenges reduce and enhance the safety and reliability of the electricity supply. This model has been tested and deployed in the water sector in Kisumu, Kenya and in Kumasi, Ghana[120].

Feasibility Study Areas:

- **Background research**: Evaluate the challenges Kenya Power faced in rolling out Delegated Management Models in Kenya.
- **Learnings**: Identify best practices and lessons learned from current delegated management models.
- **Implementation plan**: Develop guidelines for establishing and managing future partnerships in other informal settlements.

6.2.2 Mobile Energy Storage Solutions

Rationale
Introducing portable power stations with battery-swapping capabilities provides flexible and affordable energy solutions for residents in informal settlements, reducing reliance on illegal connections. In Nairobi, Kenya, battery-swapping stations have emerged as a game-changing solution to accelerate the transition to electric mobility, particularly for the city's widely used motorcycle taxis. For instance, through the Charge up partnership, led by organizations such as Energy 4 Impact, ARC Ride, and Fika Mobility, a Battery-as-a-Service (BaaS) model was introduced to address the high upfront costs of electric motorcycles, where batteries typically account for 40% of the vehicle's cost[121].

Feasibility Study Areas:

- Assess the applicability of battery-swapping technology for household energy needs.
- Identify potential partners and stakeholders for implementing portable power stations.
- Evaluate the economic viability and sustainability of such solutions in informal settlements.

6.2.3 Hardware Advanced Solutions

Rationale
Deploying advanced hardware solutions in urban Medium Voltage (MV) and Low Voltage (LV) distribution networks (cables, transformers, cabins) can significantly enhance grid performance, and increase power delivery capacity.

Feasibility Study Areas:
- **Site selection**: Determine optimal locations for hardware upgrades based on demand analysis.
- **Technology assessment**: Assess the technical requirements and costs associated with deploying hardware upgrades in densely populated areas.
- **Implementation plan**: Develop a phased implementation plan prioritizing areas with the most pressing needs.

6.2.4 Advanced Metering Infrastructure (AMI)

Rationale
Implementing AMI (both equipment and software) enhances the monitoring and management of electricity usage, detects illegal connections, and ensures accurate billing. This technology can significantly reduce commercial losses and improve revenue collection.

Feasibility Study Areas:
- **Deployment**: Assess the scalability of AMI deployment to include residential areas, especially informal settlements and peri-urban areas.
- **Viability**: Evaluate the cost-benefit analysis of widespread AMI implementation.
- **Challenges**: Identify potential challenges in AMI adoption and develop mitigation strategies.

6.3 Johannesburg

Johannesburg, South Africa's largest city, faces significant challenges in providing reliable electricity access to its residents, particularly those in informal settlements. These challenges stem from a combination of aging infrastructure, frequent power outages, and a high prevalence of illegal connections, which not only compromise safety but also lead to substantial revenue losses for the utility. According to City Power's quarterly report, there were 1,407 power cuts recorded between 1 January and 28 May 2021, excluding scheduled load-shedding, mainly attributed to deteriorating infrastructure and power surges triggered by frequent load-shedding[122].Rapid urban expansion and financial constraints further complicate the situation, limiting the city's ability to upgrade and extend its electricity distribution network. To address these issues, the following four solutions are recommended for further feasibility studies, each with its rationale and targeted focus areas.

6.3.1 Solar hybrid mini-grids and micro-grids

Rationale
Micro-grids powered by renewable energy sources, such as solar, offer a sustainable and decentralized approach to electrifying underserved areas. They can operate independently or in conjunction with the main grid, providing reliable power to communities that are difficult to connect through traditional infrastructure.

Feasibility Study Areas:

- **Site Selection**: Identify informal settlements and peri-urban areas where micro-grids would be most effective.
- **Technical Design**: Assess the optimal mix of renewable energy sources and storage solutions to ensure consistent power supply.
- **Financial Viability**: Evaluate funding mechanisms, potential partnerships, and cost-recovery models to sustain micro-grid operations.
- **Regulatory Compliance**: Ensure alignment with national energy policies and obtain necessary approvals from relevant authorities.

6.3.2 Advanced Metering Infrastructure (AMI)

Rationale

AMI systems enable accurate measurement of electricity consumption, reduce non-technical losses, and enhance customer billing transparency. By detecting and preventing illegal connections, AMI contributes to improved revenue collection and grid stability.

Feasibility Study Areas:

- **Technology Evaluation**: Assess the suitability of various AMI technologies and vendors for the local context.
- **Pilot Programs**: Implement AMI in selected areas to evaluate performance, customer acceptance, and operational challenges.
- **Cost-Benefit Analysis**: Analyse the financial implications, including potential savings from loss reduction against implementation costs.
- **Regulatory Framework**: Ensure compliance with data protection laws and establish protocols for data management and security.

By conducting these feasibility studies, cities can develop targeted, sustainable electricity access projects that improve energy reliability, economic growth, and social development.

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Annexes

Annex 1: Electricity Access Profiles: Key Selected Cities in Sub-Saharan Africa

Annex 1 presents a detailed analysis of the 10 selected cities, highlighting the key challenges, regulatory environments, ongoing initiatives, and investment opportunities. It also provides estimates of the required investments to improve electricity access and reliability in urban and peri-urban regions.

Johannesburg, South Africa

<table>
<tr><td>Population:
District City of Johannesburg
Population 2024: 6.32 million

Population Growth Rate: 0.8% annual growth

Population living in informal settlements:
9.7%[124]</td><td>Population with access to electricity:
5,947,120
94.1% [124]

Population without access to electricity:
378,568
NB: 5.99%</td></tr>
<tr><td colspan="2">Current grid operators:
1. Eskom, South Africa’s state-owned utility company, holds a significant role in the nation’s energy landscape, functioning as a vertically integrated quasi-monopoly entity:
• National Transmission Company of South Africa (NTCSA): As part of Eskom's unbundling process, the NTCSA was established as a wholly owned subsidiary to manage the national transmission system.
• Eskom Renewable Energy Unit: Collaborates on hybrid mini-grid and renewable projects to support rural communities</td></tr>
<tr><td colspan="2">Other electricity service providers (Solar Home Systems, mini grids, virtual power plants etc):
1. Solar Home Systems[125]
• Schneider Electric
• ARTsolar Pty Ltd
• Canadian Solar Inc.
• Eaton Corp. Plc
• Enel Spa
• Ener G Africa
• Energy Partners Solar Pty Ltd
• ENGIE SA
• FOXESS CO. LTD.
• Genergy
• IBC SOLAR AG
• Jetion Solar China Co. Ltd.
• Jiangsu Seraphim Solar System Co. Ltd.
• Jiangsu Zhongli Group Co. Ltd.
• JinkoSolar Holding Co. Ltd.</td></tr>
</table>

- Renenergy
- Schneider Electric SE
- Sharp Corp.
- Soventix GmbH
- SunPower Corp.
- Trina Solar Co. Ltd

2. Mini grids companies/developers
    - African Mini Grids
    - African Minigrids
    - Sustain Solar
    - Sustain Solar
    - WiSolar
    - City Power

3.Virtual Power Plants

- Rubicon Group: Engaged in Virtual Power Plant (VPP) solutions integrating solar PV, battery storage, and advanced software to stabilize grids.
- SolarMD: Provides software-driven energy storage systems that can be integrated into VPP models.

Key Challenges in Accessing Electricity

- Aging Infrastructure and poorly performing coal-fired power stations.
- Rising cost of grid electricity and municipality budgetary constraints.
- Grid congestion & connection backlog.
- Delays in implementation of mega-build programmes including the renewables projects as part of the renewable energy independent power producer procurement programme (REIPPPP)[127]
- Eskom financial challenges, and a failing municipal electricity distribution business model.
- The research findings reveal that residents of the City of Johannesburg are only able to access electricity for an average between 7-12 hours in a day due to energy shortages[126]
- Lack of adequate systems to manage grid capacity and mitigate blackouts exacerbates the issue of energy insecurity

Areas for Intervention

A. **Hardware Investments:**

1. Infrastructure Upgrades:
    - New power plants, including renewables.
    - Upgraded T&D networks, substations, mini-grids and backup generators.
2. Maintenance:
    - Refurbishing aging power stations and regular maintenance of grid components.
3. Energy Storage and Mini-Grids:
    - Building mini-grid systems for small communities or industrial parks
4. Renewable Energy:
    - Solar PV, wind turbines, micro-hydropower and biomass for off-grid solutions.

B. **Software Investments:**

1. Grid Management System:
    - Real-time monitoring and demand response
2. Data Analytics:
    - Predictive maintenance and load forecasting.
3. Customer Management:
    - Upgraded billing systems and engagement platforms.
4. Planning and deploying microgrids can mitigate energy blackouts by localizing energy generation and storage, ensuring more reliable electricity supply.

C. Other Areas

1. Using data centres to monitor electricity demand in real time across the city's 135 wards can help optimize resource allocation and identify suitable sites for battery storage[126].
2. Embedding energy planning into IDP programs can streamline efforts to secure energy supply and align them with broader municipal development goals.

Regulatory Authorities:

1. National Energy Regulator of South Africa (NERSA)
2. Minister of Mineral Resources and Energy

Abidjan, Côte d'Ivoire

<table>
<tr>
<td>Population: 5.86 million (2024)

Population Growth Rate: 3.19% per year

Population living in informal settlements:
Data is not available
NB: Studies reveal the existence of 137 informal neighbourhoods representing nearly 20% of the city's population (Abidjan)[52]</td>
<td>Population with access to electricity:
5,508,406
Estimated. [50]

72.8% of homes are connected to the public electricity network[50]
Urban Electrification Rate 94%
Rural Electrification Rate 42% [128]

**Number of people without access to electricity
NB: no data</td>
</tr>
<tr>
<td colspan="2">Current grid operators:
1. State owned generation, transmission and distribution companies:
• Compagnie Ivoirienne d’Électricité (CIE)
• Côte d’Ivoire Energies (CI-ENERGIES)
2. Independent Power Producers (IPPs):
• Compagnie Ivoirienne de Production d’Electricité (CIPREL)
• Azito Energie
• Aggreko
• CI-ENERGIES (also acts as an IPP)
• CIPREL</td>
</tr>
<tr>
<td colspan="2">Other electricity service providers (Solar Home Systems, mini grids, virtual power plants etc):
1. Solar Home Systems
• Bboxx Côte d’Ivoire
• EDF Côte d'Ivoire
• Fortune CP
• Solar Power Solutions Pvt Ltd
• Masolar
• Enfsolar
• Total Energies Côte d'Ivoire</td>
</tr>
<tr>
<td colspan="2">Key Challenges in Accessing Electricity:

• Côte d’Ivoire suffers from insufficient electricity infrastructure, which hampers efforts to achieve universal access and support economic growth.
• The need to transmit large quantities of energy over long distances from centralized power sources to rural areas creates inefficiencies and high costs. Decentralized solutions, although potentially more economical in isolated areas, are often deprioritized.
• Rapid increases in electricity demand are expected due to population growth (from 26 million to 51 million by 2050) and projected GDP growth, placing significant pressure on the existing system.</td>
</tr>
</table>

- The country has limited domestic coal resources, making it reliant on imported coal, an arrangement that raises concerns about energy security and cost stability. If coal is used to offset declining natural gas reserves, it could lead to a fivefold increase in CO_2 emissions[129].
- Transitioning to sustainable technologies requires highly skilled engineers and specialized expertise, which may not currently be sufficient, creating potential human capital bottlenecks.
- Both technical losses (due to energy dissipation in conductors and transformers) and non-technical losses (caused by metering issues, invoicing errors, or fraud) contribute to significant energy inefficiency in Côte d'Ivoire's transmission and distribution system.
- In 2016, total energy losses were approximately 20%, well above the target of 12%. This resulted in around 2,000,000 MWh of energy being lost, translating into a loss of US$150 million[130].
- The energy losses are disproportionately higher in Abidjan compared to inland areas, which suggests regional inefficiencies and potential issues with infrastructure or management in urban centres.

Areas for Intervention:

A. Hardware Investments

1. Grid Infrastructure
    a. Expansion of power plants:
        - Solar PV farms, hydroelectric facilities, and modern thermal power plants.
    b. Transmission and Distribution Networks:
        - Upgrading existing transmission lines and expanding grid coverage to rural and peri-urban areas.
        - Substations, transformers, and switchgear equipment.
        - Smart grid technology to enhance efficiency and reliability.
    c. Storage Solutions:
        - Large-scale battery storage to support intermittent renewable energy sources like solar.
        - Pumped hydro storage for load balancing.
2. Off-Grid Infrastructure
    a. Solar Home Systems (SHS):
        - Panels, batteries, inverters, and charge controllers.
    b. Mini-Grids:
        - Community-level microgrids powered by solar PV or hybrid systems (solar-diesel, bioenergy).
        - Distribution lines within communities.

B. Software Investments

1. Grid Management:
    a. Energy Management Systems (EMS):
        - Real-time monitoring and control software to optimize grid operations.
        - Predictive analytics tools for load forecasting and maintenance.

- Integrated billing platforms with smart metering solutions.

2. Off-Grid Management:
    a. Remote Monitoring Systems:
    b. IoT-based solutions to monitor performance and maintenance needs of SHS and mini-grids.

C. Other Areas:

1. Mobile Payment Platforms:
    - Pay-as-you-go (PAYG) solutions for off-grid consumers to ensure affordability and payment flexibility.
    - Distributed generation will receive a guaranteed feed-in tariff for 5 to 10 years, based on technology and capacity. Grid-connected systems (0.5–1 MW) and mini-grid systems (0.2–0.5 MW) will have tariffs set by ministerial order[130].

Regulatory Authorities:

1. Ministry of Petroleum, Energy, and Renewable Energy: Oversees the energy sector, including policy formulation and strategic direction.
2. Côte d'Ivoire Energies (CI-ENERGIES):
    - Handles the expansion and reinforcement of infrastructure.
    - Produces and sells electricity.
3. National Electricity Regulatory Authority of Côte d'Ivoire (ANARE-CI): Ensures compliance with laws, regulations, and contracts.
4. Ivorian Electricity Company (CIE):
    - Operates public assets for electricity generation, transmission, import/export, and distribution.
    - Provides service to end customers.

Nairobi, Kenya

Population: Nairobi 5.54 million (2024) **Population Growth Rate:** Intercensal Growth Rate 2.2 **Population living in informal settlements:** 3.1 million population 50-60% share of Nairobi residents living in informal settings[131]	**Population with access to electricity**: 5,401,500 **NB**: The IEA's World Energy Outlook also estimated that more than 97.5% of the urban population in Kenya had access to electricity in 2024 compared to 65% in rural areas. In Nairobi, electricity access increased from 72.4% in 2009 to 97.5% in 2022 In 2022 Nairobi had **2,775,550** Customers Connected to Electricity[132]. **Population without access to electricity:** 138,500

Current grid operators:

1. Generation Companies
    a. Public Owned:
        - Kenya Electricity Generating Company PLC (KenGen)
    b. Independent Power Producers (IPPs): Contribute about 10% of installed capacity, playing a critical role in diversifying the energy mix. Key IPPs in Kenya include:
        - Lake Turkana Wind Power
        - Kipeto Wind Battery
        - Rabai Power Limited
        - Thika Power Ltd
        - Gulf Power Ltd
        - Triumph Generation Company
        - Tsavo Power Company Ltd
        - Iberafrica Power Ltd
        - Other smaller projects (solar/hydro)
2. Distribution System Operator:
    a. Public Owned:
        - Kenya Power and Lighting Company (KPLC)
    b. Private owned:
        - Two Rivers Power Company, servicing the Two Rivers Development real estate.
        - Tatu City Power Company, supporting the Tatu City development.
        - Erdemann Property Limited, managing distribution in Greatwall Gardens
3. Transmission Service Operators:
    - Kenya Electricity Transmission Company Limited (KETRACO)

Other electricity service providers (Solar Home Systems, mini grids, virtual power plants etc):

1. Solar Home Systems:

- SunKing
- Engie Energy Access (Mysol, Fenix International etc)
- Bboxx
- Zola
- D-light

2. Mini grids
   - PowerGen
   - Powerhive
   - SteamaCo
   - Vulcan

Key Challenges in Accessing Electricity:

1. Poverty: Most slum residents have very low incomes to afford electricity connection.
2. Land Tenure: Many slum dwellers, like those in Kibera, do not own the land they live on. The government owns the land, making it difficult for residents to secure bank loans for electricity connections due to a lack of collateral.
3. High Population Growth-Rate:
   - Growth rate at 2.2% with the number of people living in slum areas projected to double in the next 15 years.
   - Factors like high living costs, limited access to formal land markets, and the fact that cities often offer better job opportunities drives rural-urban migration, leading to overcrowding in slums near town centres.
   - Informal settlements are often on government land reserved for future developments, leading to contested spaces and deteriorated living conditions[133].
   - KPLC finds it difficult to calculate the actual power demand due to illegal connections causing system overload[133].
4. Unplanned structures and narrow roads and alleys leave insufficient space for electricity infrastructure.
5. Grid expansion has outpaced the utility's ability to maintain hierarchical control and coordination, creating unregulated spaces. These gaps lead to contested territories where informal actors have stepped in assuming roles like last-mile connections, system repairs, and even local governance.
6. Cartels in slums redistribute electricity illegally, exploiting the utility's lack of control.

Areas for Intervention:

A. Hardware Investments:

1. Infrastructure Upgrades:
   - Invest in robust power lines and transformers to handle increased load and prevent overloads.
   - Construction of new substations or upgrading existing ones to manage power distribution efficiently.
   - Use of Advanced metering infrastructure (AMI) to monitor and manage electricity

usage, detect illegal connections, and ensure accurate billing.
- Underground Cabling: Investment in underground cabling to save space and reduce the risk of damage or theft.
- High-capacity transformers, small-scale transformers and flexible grid systems to support growing demand.
- Small-scale transformers and insulated cables that fit narrow spaces.

B. Software Investments:

1. Demand Management Systems.
2. Software to accurately predict power demand and manage load distribution detect and mitigate illegal connections, ensuring system stability.

C. Other Areas

1. Off-Grid Solutions:
   - Accelerate the development of mini grids that generate and distribute power locally, independent of the main grid.
   - Development of hybrid systems where solar, wind, and battery storage are synchronised for a more reliable off-grid solution.
2. Energy-Efficient Appliances:
   - LED Lighting

Regulatory Authorities:

1. Ministry of Energy: Sets national energy policies and oversees the development and management of energy resources.
2. Energy and Petroleum Regulatory Authority (EPRA): Regulates the entire energy sector, including electricity tariffs, licenses, and quality standards.
3. Electricity Sector Associations: Include the Association of Power Utilities of Africa and Kenya Renewable Energy Association (KEREA), advocating for renewable energy development.

Lagos, Nigeria

Population: Estimate 16.54 million (2024) **Population Growth Rate:** The annual growth rate of the population in Lagos from 2006 to 2019 is approximately 2.8%. **Population living in informal settlements:** More than 60% of Lagos' population resides in informal settlements dispersed throughout the city, with a significant concentration in Makoko, which is home to approximately 300,000 people[44].	**Population with access to electricity:** 15,878,400 The draft Lagos IRP load forecast estimates that 31% of households in Lagos were connected to the national grid in 2020 based on the total number of registered customers[134]. **Population without access to electricity:** 661,160 **NB:** Approximately 4% of Lagos' population is not connected to the grid, while around 60% have limited access to grid electricity[135]. This implies that currently, 69% of households in Lagos are effectively unconnected or off-grid[134]

Current grid operators:

1. Generation Companies
    - Kainji Jebba Power Plc
    - Ughelli Power Plc
    - Sapele Power Plc
    - Egbin Power Plc
    - Niger Delta Power Holding Company
    - Shiroro Power Plc
    - Afam Power Plc Gas
    - IPP's Gas
2. Distribution System Operators (DSOs):
    - Ikeja Electricity Distribution Company Limited
    - Eko Electricity Distribution Company Limited
    - Abuja Electricity Distribution Company Plc
    - Port Harcourt Electricity Distribution Company Plc
    - Kaduna Electricity Distribution Company Plc
3. Transmission System Operators (TSOs)
    - Transmission Company of Nigeria (TCN)

Other electricity service providers (Solar Home Systems, mini grids, virtual power plants etc):

1. Azuri
2. D. Light Limited
3. Lumos
4. Oolu Solar
5. Greenlight Planet (Sun King)

6. Rooftop1
7. A4&T
8. Arnergy
9. Asteven Engineering
10. Auxano Solar
11. Daystar Power Solution
12. Rubitec Solar
13. Rensource
14. Schneider Electric
15. Smarter Grid International
16. Solynta Energy
17. Starsight Energy
18. Zola Electric

Key Challenges in Accessing Electricity:

1. Inadequate Power Supply and high commercial losses:
    - The total generation capacity dispatched into Lagos State from the national grid is rarely more than 1000 MW on a typical day, over an average of 12 hours daily. This is grossly inadequate for a population of over 12 million.
2. High Demand, electricity theft and unmetered connections:
    - A study by the Lagos State Electricity Board (LSEB) in 2014 reported that Lagos State has a total off-grid generator capacity of approximately 15,000 MW, indicating a level of demand that is currently beyond the capacity of the two DSOs (Eko and Ikeja).
    - Electricity theft among the households in Lagos State, Nigeria, remains significantly high, with an estimated prevalence of 14%. Urgent measures are required to address this issue by tackling the factors that drive consumers to engage in such practices[136].
3. Reliance on Backup Generators:
    - Due to the inadequate supply from the DSOs, socio-economic activities in Lagos State are heavily reliant on a fleet of power backup generators and renewable energy systems.
    - Despite having the infrastructure to generate 13GW, Nigeria's ageing grid can only distribute one-third, leading many to rely on expensive fuel generators[137].

Areas for Intervention:

A. Hardware Investments:

1. Transmission Infrastructure:
    - Upgrading and expanding transmission lines and substations to handle increased power generation and distribution.
2. Distribution Infrastructure:
    - Expansion and upgrade of distribution networks to reduce losses and improve service delivery.
    - Deployment of advanced metering infrastructure (AMI) to ensure accurate billing

and reduce theft.

- Installation of new transformers and distribution substations to meet growing demand

B. Software Investments:

1. Demand Management Systems:
    - Load Forecasting Tools to accurately predict power demand and manage load distribution.
    - Advanced analytics to detect and mitigate illegal connections, ensuring system stability.
    - Prepaid Metering Solutions: manage prepaid metering making it more affordable and accessible for low-income residents.

C. Other Areas

1. Off-Grid Solutions
    - Hardware and software investments
2. Renewable Energy Systems:
    - Installation of solar panels on individual homes or community-shared systems.
    - Small-scale wind turbines
    - Micro-hydropower plants
3. Mini grids:
    - Setting up mini grids that can generate and distribute power locally, independent of the main grid.
    - Installation of hybrid systems combining solar, wind, and battery storage for a more reliable off-grid solution.
4. Energy-Efficient Appliances:
    - LED lighting
    - Efficient cookstoves
5. Battery Storage:
    - Community Battery Systems: Investment in community-scale battery storage systems to ensure continuous power supply.

Regulatory Authorities:

1. Federal Ministry of Power: Policy formulation and consistency
2. Nigeria Electricity Regulatory Commission: Issuance of licenses and regulation
3. Nigeria Bulk Electricity Trading Company Plc: Power purchase agreements
4. Nigeria Electricity Liability Management Company: Mandated to take over management and settlement of power purchase agreement obligations and other legacy debts.
5. Bureau of Public Enterprise: Support privatization of Nigerian legacy assets
6. Gas Aggregation Company of Nigeria: Allocation of gas for domestic use
7. Transmission Company of Nigeria: Management of the national grid
8. Nigeria National Petroleum Company: Gas infrastructure and transportation
9. Rural Electrification Agency: Remote and off grid projects

10. Nigerian Electricity Management Services Agency: Testing and certification of electrical components for quality and suitability[138]
11. Advisory Power Team (Vice President's Office): Facilitating cross-sector solutions
12. Federal Government of Nigeria Power Company: Power project supervision and monitoring

Addis Ababa, Ethiopia

Population: more than 5.7 million (2024) **Population Growth Rate:** 2% annual growth rate from 2007 to 2013 **Population living in informal settlements:** around 70-80% of Addis Ababa's housing stock is estimated to be in "slum conditions" [48]	**Population with access to electricity:** High* Addis Ababa had almost 100% access[106] Ethiopia currently has an electricity access rate of 45%, 11% of its population already have access through decentralised solutions[139]. **Population without access to electricity:** Low* About 56% of the total population have no access to any form of electricity[140] **NB:** '* 'Data not available

Current grid operators:

1. Generation and Transmission System Operators:
   a. Ethiopian Electric Power (EEP)
      - Generation: Administers state-owned power plants and buys power from Independent Power Producers (IPPs).
      - Transmission: In charge of transmitting all power across the nation; owns and operates all long-distance power transmission lines.
      - Power Procurement: Buys power from IPPs.
2. Distribution System Operators (DSOs)
   a. Ethiopian Electric Utility (EEU):
      - Power Procurement: Bulk purchases power from EEP.
      - Distribution and Retail: Sells power to customers.
      - Investment Promotion: Promotes investment in the power sector.
3. Independent Power Producers (IPPs): Generate power and sell it to EEP.

Other electricity service providers (Solar Home Systems, mini grids, virtual power plants etc):

1. Rensys Engineering & Trading PLC: Rensys is an energy solutions provider that focuses on renewable energy for energy-deprived communities. They have electrified millions through solar home systems (SHS), mini-grids, and solar lanterns.
2. Gorgeous Solar Solution: This company specializes in off-grid solar solutions for rural communities across Ethiopia.
3. Green Scene International: Founded in 2016 and led by women, Green Scene focuses on delivering renewable power to off-grid communities.
4. STM Solar Technologies Manufacturing: STM is recognized as the first private Ethiopian company to produce solar lamps and home systems specifically designed for rural households.

Key Challenges in Accessing Electricity:

1. Poor Connectivity: Weak connectivity between national systems of cities.

2. Illegal Connections: A significant number of households are illegally connected to the electricity supply, tapping from neighbours without a legal contract agreement from the sole electric distributor, EEU.
3. Voltage Drop and Saturated Transformers: Voltage drop, and saturated transformers are classical problems due to illegal connections and overloading.
4. Infrastructure Rehabilitation Needed: EEU needs to conduct rehabilitation of medium and low voltage lines.
5. There is a need to erect additional support or upgrade transformer capacity to increase the number of connected households or customers[141]
6. Financing: Investment Gap: A large financing gap exists because current spending focuses on maintenance and operation, with little left for long-term investments and addressing the power supply gap.
7. High Costs of Supplying Rural and Peri-Urban Households: Low Population Density and High Poverty Rates: Rural and many peri-urban areas have low population density and a high percentage of poor households, leading to limited demand for electricity.
8. Lack of Appropriate Incentives: The high costs of electricity supply in rural areas and the limited capacity of households to pay make it difficult to attract investment in rural electrification.
9. The connection fee of USD 150 per household is prohibitively high for many, especially considering the low average household income[142]
10. Despite relatively affordable electricity tariffs (USD 0.0765/kWh as of 2021), the last-mile connection costs pose significant barriers.
11. The high import duties and VAT on essential electrical goods hinder widespread adoption and increase costs for consumers.
12. Terrain slope and land cover significantly raise grid extension costs, with geospatial factors increasing costs by 2.3%–29% depending on location[142]
13. Rapid demand growth without proper planning results in high burnout of transformers, breach of thermal limits of conductor's frequent failure of protection equipment.
14. Restrictive business, licensing, and investment regulations limit innovative models like mini-grids and PAYGO systems[142]
15. End-user prices for standalone solar solutions in Ethiopia are among the highest in the region.
16. Informal settlers often live in areas that are not zoned for residential use, meaning they lack legal entitlement to connect to formal energy providers. This creates difficulties for integrating them into formal energy supply networks.
17. Energy suppliers are reluctant to invest in infrastructure for informal settlements due to factors such as the socio-economic status of the residents, low electricity consumption, and unreliable demand patterns[143]
18. The government has been slow to expand electricity access to informal settlements, with insufficient focus on off-grid energy solutions
19. Lengthy administrative processes discourage households from seeking or maintaining electric connections

Areas for Intervention:

A. **Hardware Investments:**

1. Distribution Infrastructure:
    - Expansion and upgrade of distribution networks in urban and peri-urban areas, focusing on Dire Dawa and other secondary cities.
    - Deployment of advanced metering infrastructure (AMI)
    - Installation of new transformers and distribution substations to meet growing demand, particularly in areas with high population density and industrial activity.
2. Transmission Infrastructure:
    - Upgrading and expanding transmission lines and substations, particularly in areas with high industrial demand and new industrial parks.
3. Off-Grid Solutions:
    - Renewable Energy Systems: Installation of solar panels on individual homes or community-shared systems, focusing on rural and peri-urban areas with low electrification rates.
    - Setting up hybrid microgrids that can generate and distribute power locally, independent of the main grid, focusing on rural and peri-urban areas with low electrification rates.

B. Software Investments:

a. Incorporate Open-Source Energy System Modelling Framework (OSeMOSYS) a tool designed for energy planning and policy decision support.
b. Incorporate Open-Source Spatial Electrification Tool (OnSSET) which supports spatial analysis of electrification options, helping to determine the most cost-effective strategies for meeting residential electricity demand.
c. Use of GIS technology to optimize planning for both grid and off-grid infrastructure[144]

C. Other Areas

1. Incorporating geospatial factors such as terrain, land cover, and LCOE (Levelized Cost of Electricity) into grid planning enhances accuracy and cost optimization.
2. Energy-Efficient Appliances: Distribution of energy-efficient lighting solutions, focusing on rural and peri-urban households with limited access to electricity.

Regulatory Authorities:

1. Ministry of Water, Irrigation, and Energy (MoWIE): Oversees the power sector at a ministerial level.
2. Ethiopian Energy Authority (EEA): Regulates the power sector and provides licenses for sector investment.

Dar es Salaam, Tanzania

Population: 8.16 million (2024) **Population Growth Rate:** average annual rate of approximately 2.11% between 2012 and 2022. **Population living in informal settlements:** Nearly 80% of land or settlements in Dar es Salaam city are informal[145]	**Population with access to electricity:** 7,099,200 Almost nine out of ten households in Dar es Salaam (87 percent) and seven out of ten in other urban areas (70 percent) are connected to electricity[146] **Population without access to electricity:** Approximately 1,060,800

Current grid operators:

1. Generation
    - Tanzania Electric Supply Company Limited (TANESCO)
    - Songas Tanzania Limited
    - Mwenga Hydro Limited
    - Andoya Hydro Electric Power Limited
    - Tulila Hydro Electric
    - Matembwe Village Company Limited
    - Yovi Hydropower Company Limited
    - Darakuta Hydropower Development Company Limited
    - TPC
    - TANWAT
2. Distribution System Operators (DSOs):
    a. Above 1 MW
        - Tanzania Electric Supply Company Limited (TANESCO)
    b. Below 1 MW
        - Mwenga Power Services Limited
        - Andoya Hydro Electric Power Company Limited
        - Powercorner Tanzania Limited
        - Jumeme Rural Power Supply Limited
        - PowerGen Renewable Energy Limited
        - E.O.N Off-Grid Solution Gmbh
        - Watu na Umeme Limited
3. Transmission Service Companies
    - Tanzania Electric Supply Company Limited (TANESCO)

Other electricity service providers (Solar Home Systems, mini grids, virtual power plants etc):

1. Mini grids
    - Powercorner Tanzania Limited
    - Jumeme Rural Power Supply Limited
    - PowerGen Renewable Energy Limited

- Watu na Umeme Limited
- Ruaha Energy Company Limited
- EON Off-Grid Solution Gmbh
- NextGen Solarwazi Limited
- Mwenga Hydro Limited

Key Challenges in Accessing Electricity:

1. Connection fees and tariffs are often unaffordable for low-income households, while subsidies for electricity providers strain financial sustainability.
2. Underinvestment in generation, transmission, and distribution infrastructure.
3. Informal settlements face issues like land tenure disputes and lack of planning, which hinder grid expansion and formal connections
4. Large geographical area and low population density make extending the traditional grid costly and inefficient.
5. Off-grid solutions involving small power producers are suggested but underutilized.
6. Frequent system failures result in about 46% of power consumption being met through off-grid self-generation.
7. While several policies and institutional frameworks exist (e.g., Rural Energy Agency and Energy Acts), implementation challenges persist, delaying tangible benefits.
8. Perception that solar energy should be free hinders willingness to pay for installation and maintenance.
9. Preference for ownership over service models has led to greater adoption of small-scale solutions like Solar Home Systems (SHS) over mini grids[147].
10. Frequent shifts in political priorities lead to instability in energy sector policies.
11. Hydrological crisis resulting from the lower water levels and a lack of oil supply

Areas for Intervention:

A. Hardware investments:

1. Predicted increases in electricity consumption signal the need for expansion in generation, transmission, and distribution infrastructure
2. Promoting off-grid solutions to reach households without electricity

B. Software investments:

1. Retrofitting manually operated hydro plants with automated digital systems to enhance operational efficiency and reduce costs.

C. Other Areas

1. Assisting with transaction advisory services for priority generation projects.

Regulatory Authorities:

1. Energy and Water Utilities Regulatory Authority (EWURA)

2. Ministry of Energy
3. Rural Energy Agency (REA)
4. National Environmental Management Council (NEMC)

Maputo, Mozambique

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Population: 1.9 million (2024)

Population Growth Rate: Population growth rate between 3.5% per annum largely due to rural urban migration[148]

Population living in informal settlements: Approximately 863,235.

It is estimated that around 60% to 76.9% of the city's urban population resides in informal settlements[149], [150].

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Population with access to electricity: 1,833,500
Approximately 96.5% of households in Maputo City have access to electricity through the national grid[151]

Population without access to electricity: 66,500

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Current grid operators:

1. Electricidade de Moçambique (EDM): EDM is the public company responsible for the production, transmission, distribution and commercialization of electricity in Mozambique. It acts as the central authority in the management of the national electricity grid and is key to the implementation of the National Electrification Strategy (ENE) 13[152]
2. Fundo Nacional de Energia (FUNAE). FUNAE is responsible for rural electrification and the development of mini-grids and solar home systems, especially in areas not connected to the national electricity grid. The agency focuses on projects that aim to increase access to renewable energy in rural areas.

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Other electricity service providers (Solar Home Systems, mini grids, virtual power plants etc):

1. Solar Home Systems
    - ENGIE Energy Access: Resulting from the merge between Fenix International, Mobisol and ENGIE Power Corner, ENGIE Energy Access is one of the main energy operators in the country, offering off-grid energy solutions[153].
    - SimSol Solar Solutions: SimSol offers a variety of residential solar systems, including all-in-one and hybrid solutions, with storage capacities ranging from 2,000 Wh to 24 kWh.
    - Solar Works: This company is known for providing affordable solar home systems, including packages ranging from bulbs and chargers to more complex systems[154]
    - TopSun Solar Mozambique: TopSun specializes in the installation and maintenance of solar systems, offering a range of products including solar panels and solar pumps.
    - Green Watts: This company is one of many suppliers operating in the solar home systems market in Mozambique, focusing on the distribution and installation of affordable solutions.
2. Mini grids
    - BDD Energia Moçambique: This company is focused on the development of mini-grids and is supported by REACT SSA.

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- RVE.SOL Soluções de Energia Rural S.A.: Developer and operator of mini grids, also supported by REACT SSA.

Key Challenges in Accessing Electricity:

1. The design and material of houses, such as reed houses, limit eligibility for electricity connection, creating inequality in energy access.
2. Housing quality improvements are closely tied to energy network access, disadvantages residents living in substandard housing.
3. The mini-grid market in Mozambique is still small and faces significant challenges, such as an uncertain regulatory framework and the need for substantial investment.
4. Unreliable electricity supply, exacerbated by extreme weather events and peak loads.
5. Mozambique's grid infrastructure is aging, encompassing substations, transmission, and distribution lines. Much of the existing infrastructure was built during the colonial era, before the country's independence in 1975.
6. Vandalism and the theft of equipment and infrastructure, such as electrical cables repurposed for making cooking pans.
7. Power theft is rampant in informal settlements as some residents tamper with meters or create unauthorized connections.
8. Poor planning exacerbated by residential extensions and commercial buildings that demand larger power transformers strain transmission and distribution systems, posing risks to public safety and causing property damage.
9. The grid operator, EDM, lacks technical capacity technical staff to perform the required maintenance, upgrades, and repairs on its aging infrastructure.
10. Electricity tariff is high beyond the reach of most city dwellers[155]

Areas for Intervention:

A. Hardware investments:

1. EDM ought to invest more on infrastructure, generation, transmission and distribution.
2. Development of more mini grids

B. Software investments:

1. Adoption of energy management systems to help curb vandalism and power theft.
2. Tools like OpenDSS (open-source distribution system simulator) and Grid Lab-D facilitate smart grid modelling and electric grid planning, improving integration with renewable sources.

C. Other Areas

1. EDM need to be transparent and fair in tariff formulation to help accelerate uptake and use of electricity.
2. Enforcement of laws on electricity: Although the Electricity Law thoroughly outlines the responsibilities and rights of both the electricity company and consumers, its enforcement remains insufficient.

3. Fostering a more favourable investment climate to enable private sector participation in expanding low-carbon electricity generation business. 4. Liberalise the electricity supply market to increase competition and diversify the electricity market.
Regulatory Authorities: 1. Energy Regulatory Agency (ARENE): ARENE is the independent regulatory body that oversees the production, transmission, distribution and marketing of electricity and liquid fuels. It is responsible for ensuring transparency in tariffs and resolving disputes between concessionaires. 2. Ministry of Mineral Resources and Energy (MIREME): This ministry is the main energy planning body in Mozambique, coordinating policies and strategies for the energy sector. 3. Mozambican Renewable Energy Association (AMER): AMER promotes the development of renewable energy in the country and facilitates the exchange of information between energy sector stakeholders.

Lusaka, Zambia

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<td>Population: 3.32 million (2024)

Population Growth Rate:
Average Annual Population Growth Rate 2010-2022 is 2.9%[61]

Population living in informal settlements:
1,909,964

As of 2022, approximately 1.9 million residents of Lusaka live in informal settlements, which constitutes nearly 62% of the city's population[40], [61]</td>
<td>Population with access to electricity: 3,207,120.

Population without access to electricity: 112,880

In Lusaka, the electrification rate is notably high, with over 96.6% of businesses surveyed reporting access to electricity. This figure suggests that only about 3.4% of businesses lack any form of electrification[156].</td>
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<td colspan="2">Current grid operators:
1. ZESCO Limited: ZESCO is the primary utility company responsible for electricity generation, transmission, and distribution in Zambia. It operates the Zambia Interconnected Power System (IPS) and manages a total installed capacity from various sources including hydro, solar, and thermal plants.
2. Copperbelt Energy Corporation (CEC): CEC is a transmission company that purchases electricity from ZESCO at high voltage and distributes it to the mining industry in the Copperbelt region.
3. Zenagamina Hydro Power Company (ZHPC): ZHPC runs a remote rural network in the Northern Province and Northwest Energy Corporation that distributes electricity to a rural mining community that is not on the ZESCO grid.
4. Lunsemfwa Hydro Power Company: Lunsemfwa Hydro Power Company Limited (LHPC), is an independent power producer (IPP) company based in the city of Kabwe in Zambia[157]</td>
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<td colspan="2">1. Other electricity service providers (Solar Home Systems, mini grids, virtual power plants etc):

2. Solar Home Systems
• ENGIE Energy Access: A leading provider of Pay-As-You-Go (PAYGO) and mini-grid solutions in Africa.
• VITALITE Zambia: VITALITE is one of the pioneers in selling solar home systems in off-grid areas. The company has secured funding to expand its operations significantly, aiming to provide solar energy solutions to low-income households across Zambia.
3. Mini grids
• ENGIE Energy Access: is constructing 15 solar mini grids in Zambia's Eastern Province as part of the Increase Access to Electricity and Renewable Energy Production (IAEREP) programme[158].
• Zambian Rising Sun Solar Energy Limited: This company is focused on scaling up access to clean energy through mini grids in various provinces[159].</td>
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- RDG Collective Limited: RDG Collective develops solar home systems and plans to expand its services with support from BGFA, targeting rural areas with new energy service subscriptions[160].
- Zengamina Power Limited: This company operates a hydropower plant and is integrating solar power generation with battery storage systems to enhance energy access in North-Western Province[161]

Key Challenges in Accessing Electricity:

1. Lack of access to reliable electricity is still a key impediment to economic growth. Companies are often forced to adopt various coping strategies such as changing business types, selecting different locations, reducing output, substituting factors, or generating power independently[156]
2. Less attention is given to supplying electricity for productive purposes.
3. Need to diversify electricity generation technologies: The country's reliance on hydroelectricity has made it susceptible to climate-related challenges[157]
4. Under investment on grid infrastructures[162]
5. There are still households living under the grid who are not connected[162]

Areas for Intervention:

A. Hardware investments:

1. Diversification of electricity generation away from hydropower. Zambia relies on hydropower for 80% of its electrical energy. The country suffers from an electricity crisis partly because of poor rainfalls[163]
2. Investment in electricity generation infrastructure is not keeping pace with rising demand for power, which is increasing by approximately 200 MW annually.
3. The country needs new transmission and distribution lines as the ageing ones further exacerbate the situation, contributing to frequent outages.
4. Development of mini grids.

B. Software investments:

1. Develop and deploy smart grid technology to enhance electricity distribution efficiency and reduce losses.
2. Introduce software for real-time monitoring and management of electricity supply and demand.

C. Other Areas

1. Electricity tariffs in Zambia ought to be cost reflective to encourage investment in new infrastructure and technology needed for sustainable energy production.

Regulatory Authorities:

1. Energy Regulation Board (ERB): ERB
2. Zambia River Authority: It is mandated to monitor the water levels in dams, and revise water allocation for hydropower generation.

Kigali, Rwanda

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<td>Population:
The City of Kigali population is 1.29 million (2024)

Population Growth Rate:
Latest findings are based on the data collected in August 2022. The analysis of the 2022 General Population Census indicates that Rwanda’s population was 13,246,394, showing an inter-censual annual growth rate of 2.3% between 2012 and 2022[164], [165].

Population living in informal settlements: 1,221,889

70% of the population lives in informal settlements[164].</td>
<td>Population with access to electricity:
1, 193, 692

The City of Kigali is composed of three Districts namely Gasabo, Kicukiro and Nyarugenge. Electricity access per district is as follows: Gasabo 89.0%, Kicukiro 92.9%, and Nyarugenge at 92.1%

The average on-grid electricity access rate for the three Kigali districts is 91.3%[166].

Population without access to electricity:
151,863</td>
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<td colspan="2">Current grid operators:
1. Rwanda Energy Group (REG)
• Subsidiary 1: Energy Development Corporation Limited (EDCL): EUCL is a state-owned vertically integrated utility tasked with providing electricity utility services through operations and maintenance of existing public generation plants, transmission and distribution networks, and retail of electricity to end-users.
• Subsidiary 2: Energy Utility Corporation Limited (EUCL): EDCL is mandated to increase investment in the development of new energy generation, transmission infrastructure and implementing electricity access projects to meet national targets[167].</td>
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<td colspan="2">Other electricity service providers (Solar Home Systems, mini grids, virtual power plants etc):
1. Bboxx: Specializes in off-grid solar solutions and energy access in rural areas.
2. Mobisol (part of ENGIE): Provides solar home systems for rural and peri-urban electrification.
3. Ignite Power: Focuses on affordable solar solutions for underserved communities.
4. Gigawatt Global: Developed one of the first large-scale solar farms in East Africa in Rwamagana.</td>
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<td colspan="2">Key Challenges in Accessing Electricity:

1. Many districts, particularly in remote, mountainous, and sparsely populated areas, have low electrification rates, with some below 55%.
2. High costs of extending the national grid to these areas due to geographical barriers and low population density[168].
3. Rural populations often have low incomes, limiting their ability to afford electricity even when it is available.
4. In areas like Gakenke, where houses are scattered and far apart, the infrastructure</td>
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required for grid electrification is costly and inefficient.

5. Even in electrified districts, energy demand in rural areas is typically low, leading to underutilization of infrastructure and lower economic returns on investments.
6. Programs aimed at reducing the cost of energy-efficient appliances could complement electrification efforts by lowering ongoing electricity costs for households.
7. The expense of building infrastructure in remote areas is disproportionately high compared to the relatively low electricity demand in these regions

Areas for Intervention:

A. Hardware investments:

1. Off-grid solutions like solar PV can be scaled up in remote and sparsely populated areas, as demonstrated by the high off-grid rates in districts like Nyaruguru.

B. Other Areas

1. Government ownership, leadership, and commitment to universal electrification.
2. Institutional strengthening and capacity building.
3. Involvement of the private sector and adoption of innovative financing mechanisms, such as pay-as-you-go solar systems, can make off-grid electricity more accessible to low-income households.
4. Establishment of clear regulations that support the deployment of new technologies is necessary to facilitate investment and operational efficiency.

Regulatory Authorities:

1. Ministry of Infrastructure (MININFRA)
2. Rwanda Utilities Regulatory Authority (RURA)
3. Ministry of Environment (MoE)
4. Rwanda Environment Management Authority (REMA)
5. Rwanda Development Board (RDB)

Kinshasa, DR Congo

Population: Kinshasa, which, with an estimated population of **17.03 million** (2024) **Population Growth Rate:** 6.6% annual growth[169] **Population living in informal settlements:** 7,950,000 75 percent of the population lives in slums[17]	**Population with access to electricity:** 7,493,200 Urban Electrification Rate 44%[77] **Population without access to electricity:** 9,536,800

Current grid operators:

1. Société Nationale d'Électricité (SNEL)

Other electricity service providers (Solar Home Systems, mini grids, virtual power plants etc):

1. Solar Home Systems
   - Bboxx: Distributes solar home systems and mini-grids, especially in rural and peri-urban areas. Focuses on provinces like Kivu, Ituri, and Tshopo.
   - Altech: Provides solar energy solutions, including home systems and lighting products. Collaborates with international financiers for rural electrification.
   - Weast Energie: Operates in both urban and rural areas, focusing on decentralized energy solutions.
   - Orange Énergie: A division of Orange Telecom, offering solar energy kits and PAYGo solutions in peri-urban areas.
2. Mini grids
   - Nuru: Focuses on solar mini-grids and aims to enhance energy access in underserved areas[170]
   - Equatorial Power: Operates mini grids that not only provide electricity but also support local economic activities through Productive Hubs[171].
   - Synoki
   - Hydroforce
   - EDC
   - Virunga Power

Key Challenges in Accessing Electricity:

1. The absence of phased urban expansion plans aligned with financing opportunities creates inefficiencies in infrastructure development and resource allocation.
2. In regions with limited investment capacity, implementing comprehensive urban planning systems is challenging.
3. SNEL, the state-owned utility, generates insufficient revenue to maintain or expand its limited and fragmented network, exacerbating the supply-demand gap.
4. Poor governance and regulatory challenges discourage private sector participation, undermining efforts to expand electricity access.
5. SNEL's operational inefficiencies and financial challenges hinder its ability to meet existing

or future electricity demand.

6. The vast size and dispersed population make national grid expansion costly and logistically challenging.
7. Persistent conflicts and a challenging economic environment create high risks for investors and hinder infrastructure development.
8. Only 5% of the installed capacity is produced by private entities, due to high regulatory and country risks and a lack of reliable demand data[172].
9. The absence of a national power transmission network limits energy distribution, with three independent interprovincial grids that fail to interconnect effectively[172]
10. The off-grid solar sector suffers from a lack of clear regulatory frameworks, fiscal incentives, and institutional capacity, stifling private sector growth.
11. A 34% import duty and 16% VAT on off-grid solar products increase costs, with exemptions granted only on a case-by-case basis through opaque procedures[173]
12. Limited consumer financing mechanisms and a weak commercial banking sector exacerbate affordability challenges for end-users.
13. No legislative frameworks exist for handling the growing electronic waste (16,050 tons annually), posing environmental and logistical challenges.
14. Insufficient information on power demand complicates strategic planning and limits the scalability of projects.
15. High capital costs, poor transport infrastructure, and inefficient administrative processes inflate the operational expenses of solar businesses.
16. Informal distributors play a significant role in off-grid and decentralized energy solutions due to the lack of extensive national grid coverage.

Areas for Intervention:

A. Hardware investments:

1. Pre-paid power systems and innovative financing structures can ensure affordability while supporting project sustainability.
2. Thermal-based Tools and Drones: Using thermal imaging and drones to inspect hotspots and detect faults or inefficiencies in the grid. Ghana and Kenya are using this technology for routine inspections.

B. Software investments:

1. Smart Metering: Piloting and scaling smart metering systems to improve revenue collection, reduce theft, and enhance billing accuracy. Countries like Benin and Kenya are already implementing these systems.
2. Smart Substations: Upgrading substations with smart technology for better monitoring, management, and fault detection. Senegal and the Democratic Republic of the Congo (DRC) are examples of countries testing this technology.
3. Fiber Optic Communication: Installing fiber optic communication systems along transmission lines to improve data transmission and network monitoring. This has been piloted in countries like Ethiopia and Kenya.

C. Other Areas 1. Mini-grids and off-grid solutions, leveraging renewable energy, offer a scalable approach to electrifying remote and underserved areas. 2. Feasibility studies, advisory engagements, and technical support from international organizations can strengthen local capacity and inform future projects. 3. SNEL needs training in implementing off-grid solutions and coordinating them with conventional distribution activities based on international best practices.
Regulatory Authorities 1. Ministry of Hydraulic Resources and Electricity (Ministère des Ressources Hydrauliques et Électricité) 2. Autorité de Régulation du Secteur de l'Électricité (ARE) 3. Agence Nationale d'Électrification et des Services Énergétiques en Milieu Rural et Périurbain (ANSER): 4. Office Congolais de Contrôle (OCC)