Boston University Institute for Sustainable Energy

Bringing Power and Progress to Africa
in a Financially and Environmentally Sustainable Manner

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Any remaining errors or omissions in this paper are solely the responsibility of the authors.

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Executive Summary

The future of electricity supply and delivery on the continent of Africa represents one of the thorniest challenges facing professionals in the global energy, economics, finance, environmental, and philanthropic communities.

Roughly 600 million people in Africa lack any access to electricity. If this deficiency is not solved, extreme poverty for many Africans is virtually assured for the foreseeable future, as it is widely recognized that economic advancement cannot be achieved in the 21st Century without good electricity supply. Yet, if Africa were to electrify in the same manner pursued in developed economies around the world during the 20th Century, the planet's global carbon budget would be vastly exceeded, greatly exacerbating the worldwide damages from climate change.

Moreover, due to low purchasing power in most African economies and fiscal insolvency of most African utilities, it is unclear exactly how the necessary infrastructure investments can be deployed to bring ample quantities of power – especially zero-carbon power – to all Africans, both those who currently are unconnected to any grid as well as those who are now served by expensive, high-emitting, limited and unreliable electricity supply.

With the current population of 1.3 billion people expected to double by 2050, the above-noted challenges associated with the African electricity sector may well get substantially worse than they already are – unless new approaches to infrastructure planning, development, finance and operation can be mobilized and propagated across the continent.

This paper presents a summary of the present state and possible futures for the African electricity sector. A synthesis of an ever-growing body of research on electricity in Africa, this paper aims to provide the reader a thorough and balanced context as well as general conclusions and recommendations to better inform and guide decision-making and action.

Major Findings

It is impossible to definitively answer in one survey paper all possible questions one might reasonably pose about the future advancement of the African electricity sector. Also, the availability and quality of data pertaining to the African electricity sector is low, which limits the depth of analysis that can be undertaken.

Even so, some notable overarching findings can be asserted, including:

- To achieve a minimal level of universal energy access across Africa, at least $20 billion per year of new infrastructure investment – comprising both generation and grid assets – will be required. To the extent that a greater degree of energy availability than minimal amounts is to be achieved for all Africans, the investment requirement would accordingly be larger – and probably substantially larger. Spread over the next few decades, the capital need is on the order of $1 trillion.

- The mix in the pace of additions of coal power plants and renewable energy projects will heavily shape the future trajectory of carbon dioxide (CO_2) emissions associated with African electricity generation. Given shortages of electricity supply across virtually all of Africa, it is implausible to expect retirement of existing fossil-fired generation assets anytime soon. However, choices on new generation will matter significantly, and major plans are underway to add coal capacity in many African nations, despite increasingly compelling economics and abundant supplies of renewable energy resources – notably, hydro, solar and wind.

- The weakness of transmission grids across Africa – particularly between countries – impedes the ability to effectively develop new large power projects, irrespective of type. This fact drives African electricity sector development towards a greater reliance on generation additions in smaller increments – which in turn provides additional impetus for the deployment of solar and wind projects that are already benefitting from declining cost trends. The advancement of energy storage technologies will also support an increasing trend towards distributed renewable energy generation assets.

- The preferable electricity sector development path for Africa is likely to be quite different for rural and urban regions on the continent. The latter will leverage the existing grid to the extent possible via refurbishments and targeted investments, while the former can take advantage of the emergence of novel distributed energy resources technologies and business models to deploy entirely new microgrids that have lower capital requirements – and thus the prospect of lower risks to investors. Over time, emergent rural microgrids and redeveloped urban grids can gradually merge into a "grid of grids" spreading out across the African continent from initial clusters of viability.

Additional Observations

Moreover, this paper offers the following general observations to help provide a proper orientation for further activities to advance the African electricity sector:

- It is neither possible nor prudent to think about the African electricity sector monolithically
- The future African electricity infrastructure must look different than today's
- Investment requirements are massive, but risks will inhibit capital attraction
- Achieving maximum beneficial impact requires great selectivity when targeting resources
- African electricity sector institutions need substantial strengthening
- Electricity sector advancement is part of a bigger whole in advancing African prosperity
- Advancing the electricity sector is first and foremost about serving the needs of Africans

Since scarcity of good data is one of the few universal truths across the African electricity sector, a geographically focused research agenda will be an essential first step for virtually any initiative, to build a robust fact base with which further analysis can be undertaken. Such research about electricity infrastructure, operations and demand would fall under three main areas of inquiry:

- How can current grid assets be leveraged more effectively?
- What should be the expansion plan for the current grid?
- How should micro-grids complement the current grid?

Introduction

The status of the electricity sector on the African continent – especially in sub-Saharan Africa (SSA) – is gaining increasing attention worldwide, and not just among economic development professionals.

The basic statistics are staggering. As the International Energy Agency (IEA) puts it, “Despite being home to almost a fifth of the world’s population, Africa accounts for little more than 3% of global electricity demand.” Of this disproportionately low figure, North African countries and South Africa consume nearly three-quarters of African electricity demand, even though SSA countries are home to over 80% of the continent’s population.[i]

These statistics imply that the enormous SSA region consumes virtually no electricity: an estimated 55% of the SSA population does not have access to any electricity supply, while the remaining 45% who are connected to an electricity network consume relatively little electricity, at least partly because electricity is frequently unavailable.[ii]

The African population is expected by the United Nations (UN) to approximately double to 2.5 billion between now and 2050.[iii] Between population growth and economic upside, Africa represents arguably the largest underserved growth market in the world. Untold trillions of dollars of potential consumer purchasing power await to be tapped.

Yet, this upside cannot be realized without a quantum leap in African electricity infrastructure: most places in Africa do not have 24/7/365 availability of electricity, a service that is essential for economic activity and mostly taken for granted in most developed economies worldwide.

The inadequacy of electricity infrastructure is both cause and effect of Africa’s economic underdevelopment. Economic output is inextricably tied to affordable and consistent availability of modern forms of energy, without which the ability for productive activity to contribute to the digitized global economy is limited.

Given economies with very low levels of purchasing power, electricity infrastructure developers face great difficulties in securing financing for new assets in SSA. Unfortunately, the risks of making long-term investments in most African nations are considerable, and a prospective asset owner cannot in practice repossess an underperforming electricity infrastructure investment.

The challenges inherent in developing the African electricity sector are compounded by the urgent need to undertake any expansion in a manner that preserves or improves environmental conditions in Africa. Africa’s unique ecosystems, critical to global biodiversity, could easily be damaged by imprudent power sector development.

Furthermore, most developed areas in Africa already suffer greatly from bad air quality, in many cases exacerbated by reliance upon diesel generators and other fossil fuel combustion with insufficient pollution controls.

In addition to local environmental concerns, the future role of the African electricity sector will be pivotal in the future trajectory of carbon dioxide (CO_2) emissions and their global impact on the pace of climate change.

To mitigate the threats posed by climate change, it is vital that the electricity sector in every part of the world quickly reduce its reliance on fossil fuels, the primary source of the CO_2 emissions that are driving climate change. Whereas most developed economies are experiencing declines in CO_2 emissions in large part because their electricity sectors are decarbonizing, there is substantial impetus to add fossil-based electricity generation capacity at a rapid pace in Africa in order to accelerate progress on improving energy access.

If Africa were to electrify in the 21st Century in a manner similar to the manner undertaken by the United States in the 20th Century, there is virtually no possibility for the world to meet global emissions targets that can limit the damages associated with climate change. This is not just an idealistic concern for Africans: as noted recently by the Brookings Institution, "Africa is the most-exposed region to the effects of climate change despite contributing the least to global warming."[iv]

The need for infrastructure deployment to provide universal energy access as soon as practically possible, while at the same time doing so in an environmentally-friendly way, has led to a bipolar vision for the expansion of the African power sector over the next few decades.

- At one extreme, some energy industry observers such as the Rocky Mountain Institute (RMI) suggest that the expansion of the Africa electricity sector will (or should) largely occur from the "bottom up" by decentralized solar and wind systems, often in village microgrids.[v] Proponents of this model for electric expansion argue that, because many of the existing large power systems in Africa are already unable to meet power demand with reliability and fiscal integrity, decentralized expansion of clean resources not reliant on existing institutions is the fastest – and in a growing number of cases, cheapest – path to clean universal energy access.

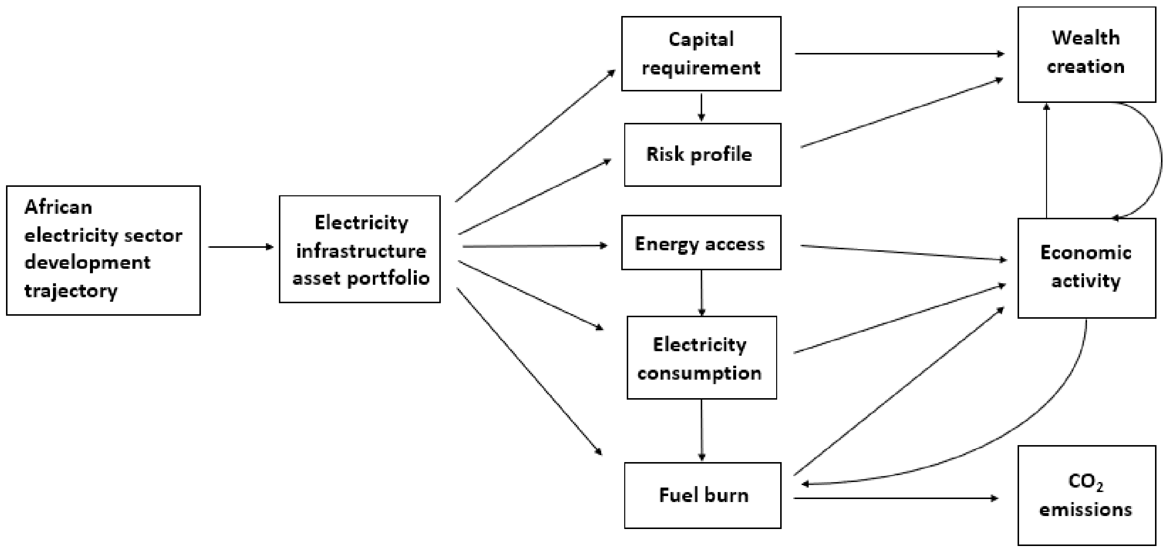
- At the other extreme, other sector development experts such as China's Global Energy Interconnection Development and Cooperation Organization (GEIDCO) envision expanding the grid in a manner that maximizes the use of Africa's abundant, high-quality renewable resources in large-scale generation basins connected by an expanded grid to deliver power to all corners of the continent.[vi] Pursuit of this vision would allow the development of massive unrealized renewable energy potential in large yet mostly unpopulated swaths of the continent, bringing ample quantities of zero-carbon and zero variable cost electricity to mega-cities, towns and villages alike in more habitable regions of Africa.

As the future unfolds, actual development of the African electricity sector is unlikely to be characterized by either of these two ends of the spectrum Rather, expansion of African electricity will undoubtedly involve a mix of approaches, including additions of both distributed and centralized electricity infrastructure assets in proportions that will vary based on many location-specific factors.

The expansion path for each country's power sector will be a unique function of national circumstances and planned economic development pathway, regional resources and institutions, and international efforts.

The importance of the electric power sector in driving economic and environmental outcomes, and the complex interaction between the many intervening variables, is illustrated in Figure 1.

Figure 1: Future Trajectory of African Electricity Infrastructure Development Will Drive African Economic Growth and Emissions



Source: ISE original

This paper addresses the intricate and intertwined nature of these important relationships, exploring the issues and implications associated with possible African electricity sector development pathways that expand energy access in a low-carbon manner.

In recent years, a large body of literature on the opportunities and challenges facing Africa's electricity sector is accumulating. Indeed, in just the four months preceding the issuance of this paper, three comprehensive reports on the African electricity sector were released:

- Africa Energy Outlook 2019 by the IEA
- Research on Africa Energy Interconnection by GEIDCO
- Sub-Saharan Market Outlook 2020 by BloombergNEF

This paper integrates and synthesizes the findings from these three studies, along with other publicly available research completed during the past several years.

Research Approach and Roadmap for This Paper

This paper aims to achieve the following objectives:

- Review the growing body of literature on Africa's electricity sector in order to:
    - Develop a set of insights and conclusions about how electricity infrastructure is likely to advance across Africa, paying special attention to the factors that will drive development towards centralized versus decentralized system growth; and
    - Identify gaps in understanding that constrain productive activities to advance electricity infrastructure enhancement in Africa
- Search for policy and market innovations that can accelerate the growth of low- and no-carbon resource additions; and

- Suggest a forward-looking research agenda to increase prospects for successful improvement in electricity sector performance wherever advancement is pursued in Africa

Despite the growing body of excellent work on the African electricity sector, developing a holistic perspective on its current status, future trajectory, and recommendations to accelerate its advancement most prudently remains a daunting task. This is for two primary reasons:

- First, there is no such thing as an "African electricity grid". Africa is an immense and immeasurably diverse continent, encompassing 54 very different countries, 1.3 billion people, and dozens of geographic zones defined more by various topographical, ecological and cultural boundaries than lines on a map. Economic integration between (and usually even within) national economies is weak: across much of Africa, the basic organizational building block of society continues to be the tribe rather than the nation, and commerce is conducted under pre-modern norms. It is therefore impossible to intelligently assess the electricity situation across Africa as one whole. Instead, scattered across the continent is a disparate collection of inconsistently developed and administered electricity activities, few of which cross national boundaries. Although there are five regional power pools across the continent, the lack of strong transmission interties has prevented them (at least thus far) from being a major force for pan-African electricity planning or operations. As a result, conclusions or recommendations pertinent to one specific locale somewhere in Africa may have limited applicability or relevance to many (or even most) other places in Africa.

- Second, the state of basic data about electricity activities in Africa is poor. In most developed economies around the world, the electricity sector is regulated and overseen by governmental authorities, and companies participating in the electricity value chain are compelled by both commercial and regulatory forces to document the basis for their investment and operating decisions. The resulting set of data and analysis about electricity sector activities is voluminous – and much of it publicly-available. This is simply not the case in Africa. Where data does exist, its quality, consistency or vintage is suspect – thus reducing the ability to perform accurate analysis or develop grounded forecasts. Anecdotal evidence is often the best-available information. So, while the volume of good research on African electricity is growing, the raw data underlying the expanding body of literature remains patchy.

Based on extensive review of the available literature (including data and analyses) on electricity in Africa and distillation of the most important findings, this paper is structured as follows:

- In Section I, the magnitude of the electricity infrastructure investment opportunity is sized at roughly $1 trillion to close of the African energy access gap – and likely much more if electricity supply availability is desired above minimal levels.
- In Section II, two emergent alternative approaches for expanding the African electricity infrastructure – centralized solar and wind energy projects and off-grid systems based on distributed energy resources (DER) – are described, including how the two will combine into a "grid-of-grids".
- In Section III, the spectrum of risks associated with electricity infrastructure investment activities in Africa is characterized.

- In Section IV, non-governmental organizations and other non-profit organizations active in the African electricity sector are profiled, including examples of the activities they are undertaking to improve the landscape for advancement.
- In Section V, conclusions are offered about the likely future evolution of the African electricity sector – emphasizing the need for market participants and researchers/advocates alike to focus on geographic areas with the greatest needs and promise for success.

I: $1 trillion Investment Need in Africa for Electricity Infrastructure

The expansion of electricity infrastructure in Africa represents the enabling foundation for unlocking heretofore untapped advancement potential of enormous magnitude. Strengthening the African electricity sector thus represents one of the world's most consequential financial, economic and social opportunities of the 21st Century.

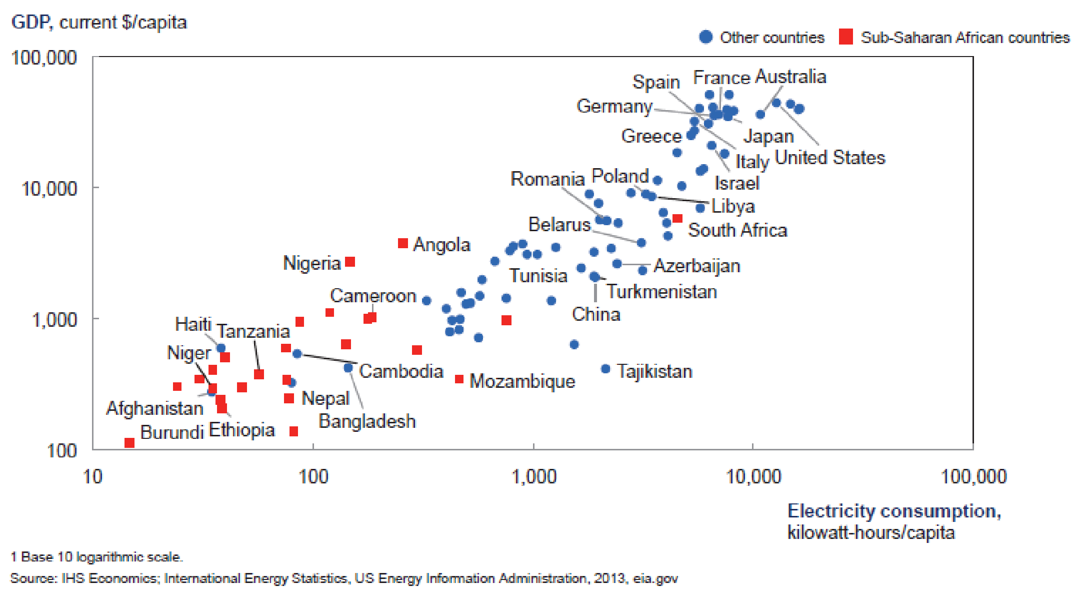
In this section summarizing the African electricity sector, the following topics will be discussed:

- How energy poverty in most African countries correlates with economic poverty
- The low rates of energy access in most African nations
- Prospects for electricity demand growth in Africa
- The current inadequacies of electricity supply infrastructure in Africa
- The role for the five regional power pools that have been established in Africa
- Projected growth in electric generating capacity in Africa and associated CO_2 emissions
- Future African electricity generation mix, particularly the roles of coal, gas and renewables
- Approximately $1 trillion of capital investments required in African electricity infrastructure

Correlation Between Economic Poverty and Energy Poverty

Especially south of the Sahara Desert, Africa suffers from both economic poverty and electricity poverty. Indeed, these two social ills are intertwined: across the globe over the past several decades, it is well-established that economic vitality and energy consumption are highly correlated. As Figure 1-1 indicates, the relationship between power and progress is strong – and many SSA nations exhibit both low electricity consumption and low per capital income relative to other countries around the world.

Figure 1-1: Strong Correlation Between National Economic Activity and Electricity Consumption (2011 Data)



Source: Brighter Africa: The Growth Potential of the Sub-Saharan Electricity Sector, McKinsey & Co, 2015

Since it is seen as both cause and consequence of Africa's depressed economic condition, significant human attention and financial capital have been and continue to be paid to expand African electricity infrastructure.

Despite increasing efforts to expand electricity infrastructure, now two decades into the 21st Century, conditions in much of Africa remain essentially at pre-industrial levels, due to the widespread lack of electricity. The summary statistics are staggering:

- 55% of the population in SSA, or roughly 600 million people, lack access to electricity.[vii]
- Per capita consumption of electricity in SSA is estimated at 484 kWh per year – only 6% of OECD country averages.[viii]

Without significant investments in electricity expansion, these statistics may worsen over the next few decades, given expected African population growth of 2.3% per year – the highest projected growth rate of any continent on Earth.[ix]

Numerous organizations around the world are mobilizing to address African electricity supply and availability deficits. To illustrate:

- The global economic development community has established an ambitious set of 17 Sustainable Development Goals (SDGs), including goal 7 (SDG7) entitled "Affordable and Clean Energy" that aims "to ensure access to affordable, reliable, sustainable and modern energy for all" people of the world by 2030.
- Organizations such as the African Development Bank (AfDB), the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), along with initiatives such as the Africa Renewable Energy Initiative (AREI), are playing ever-increasing roles in promoting advancement of the African electricity sector.
- More recently, the Rockefeller Foundation has partnered with the MIT Energy Initiative to form the Global Commission to End Energy Poverty (GCEEP), specifically aiming to address the particularly vexing challenge of bringing electricity to villages not currently served by the grid.

To provide ample supplies of zero-carbon and affordable energy to all, the portfolio of electricity assets in Africa not only must be dramatically expanded but must also be radically reshaped – with the new assets looking substantially different from the existing infrastructure. Bringing power and progress to the African continent for the 21st Century thus represents a massive investment opportunity.

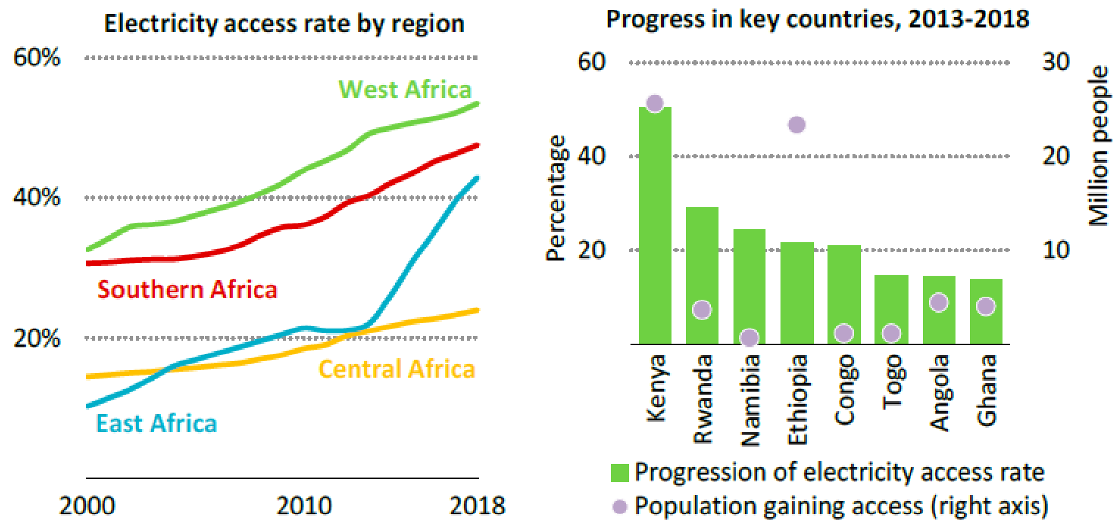
Low Rates of Energy Access

While the concept is subject to imprecision, the phrase "energy access" implies at least a minimal degree of electricity available to customers so that they can power at least a few appliances at least some of the time. In other words, customers with electricity access can use more than merely battery-powered lights or radios.

The IEA has estimated that about half of the population across Africa does not currently have access to any electricity. Although the statistics remain startling, this is nevertheless a notable improvement in the two decades since the new millennium, when roughly 2/3 of the African population lacked electricity.[x]

Electricity access statistics at the continental level mask very large disparities across the continent. For instance, in Northern Africa, electricity access is now nearly universal. In contrast, in SSA, most people (55%) do not have access to electricity.[xi] As shown in Figure 1-2, within SSA, progress to improve energy access has been most pronounced in East Africa, while Central Africa lags the most.

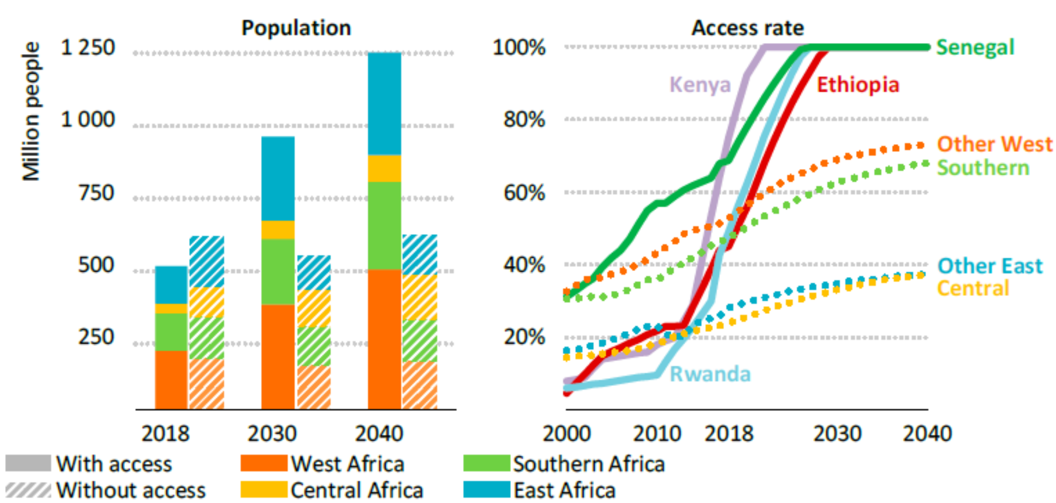
Figure 1-2: Recent Improvements in Energy Access Rates Across Sub-Saharan Africa



Source: Africa Energy Outlook, IEA, 2019

However, because of expected population growth over the coming decades, continuation of current programs to improve energy access will just hold constant (at roughly 600 million) the absolute number of Africans without electricity access. Put another way, Figure 1-3 shows that, under the status quo, energy access rates will still fall well short of 100% through 2040 in many parts of Africa – despite the fact that several African countries have established targets to provide universal (or near-universal) access before then.

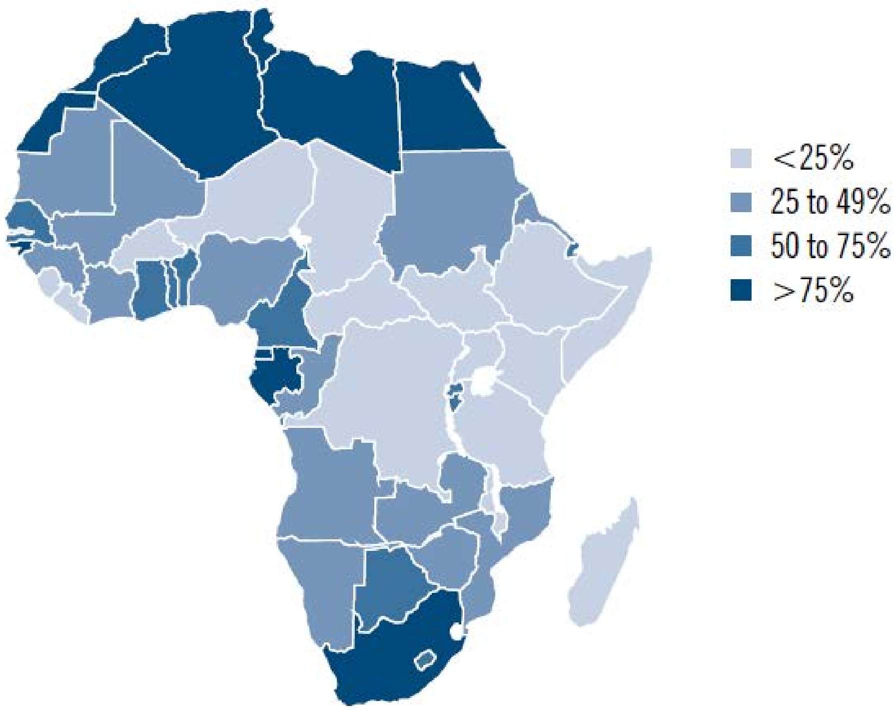
Figure 1-3: Projected Energy Access Rates in Africa Through 2040



Source: Africa Energy Outlook, IEA, 2019

The disparities in energy access rates across Africa are even more extreme at the country level, as shown in Figure 1-4.

Figure 1-4: Energy Access Rates for African Nations in 2015



Source: AIE, BAD.[13]

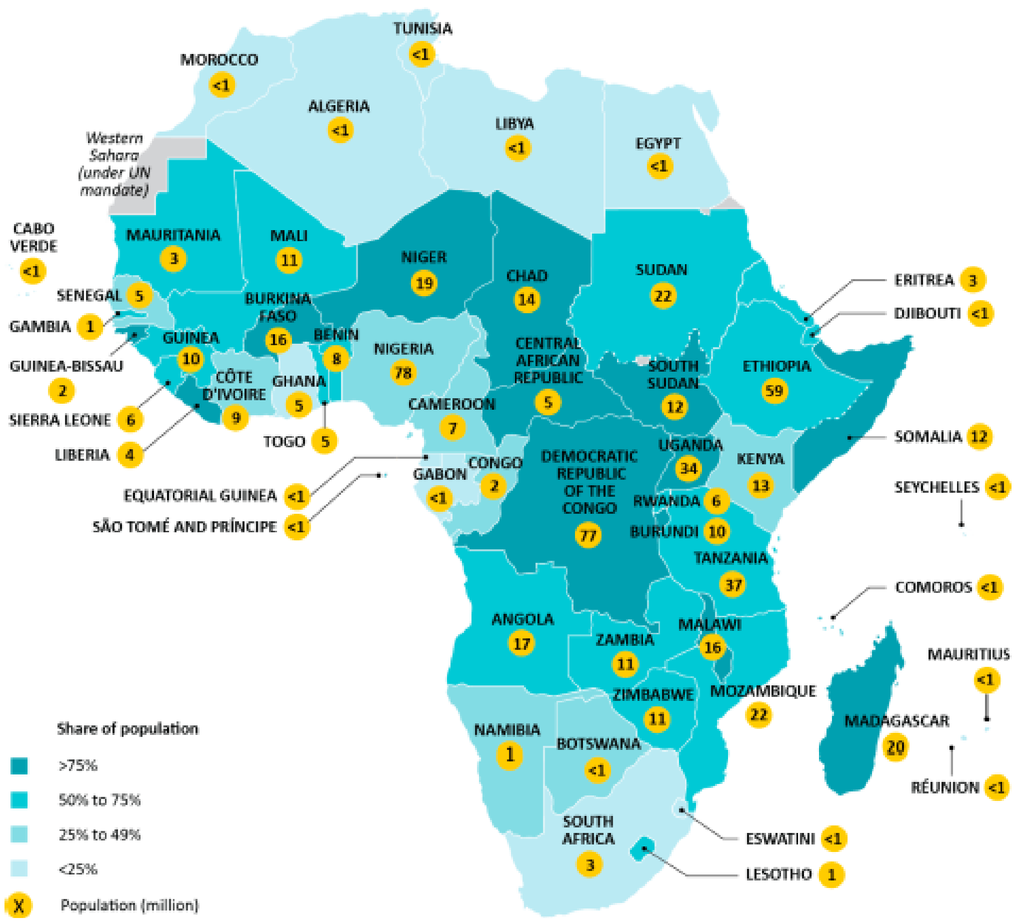
Source: Bright Perspectives for Solar Power in Africa?, Institut Montaigne, 2020

Even in the relatively wealthy country of the Republic of South Africa (RSA), more than 10% of the population lacks electricity. Meanwhile, in four countries (Central African Republic, Chad, Sierra Leone and South Sudan), more than 90% of the population lives without electricity. Indeed, in South Sudan, there is virtually no electricity available.[xii]

Consequently, large numbers of citizens in most SSA countries lack energy access. As shown in Figure 1-5, the five African countries with the largest number of citizens lacking access to electricity are:

- Nigeria (78 million)
- Democratic Republic of the Congo (77 million)
- Ethiopia (59 million)
- Tanzania (37 million)
- Uganda (34 million)

Figure 1-5: Population Without Energy Access in African Nations in 2018



In sub-Saharan Africa 55% of people lack access to electricity; in thirteen countries, more than three-quarters of the population do not have access to electricity

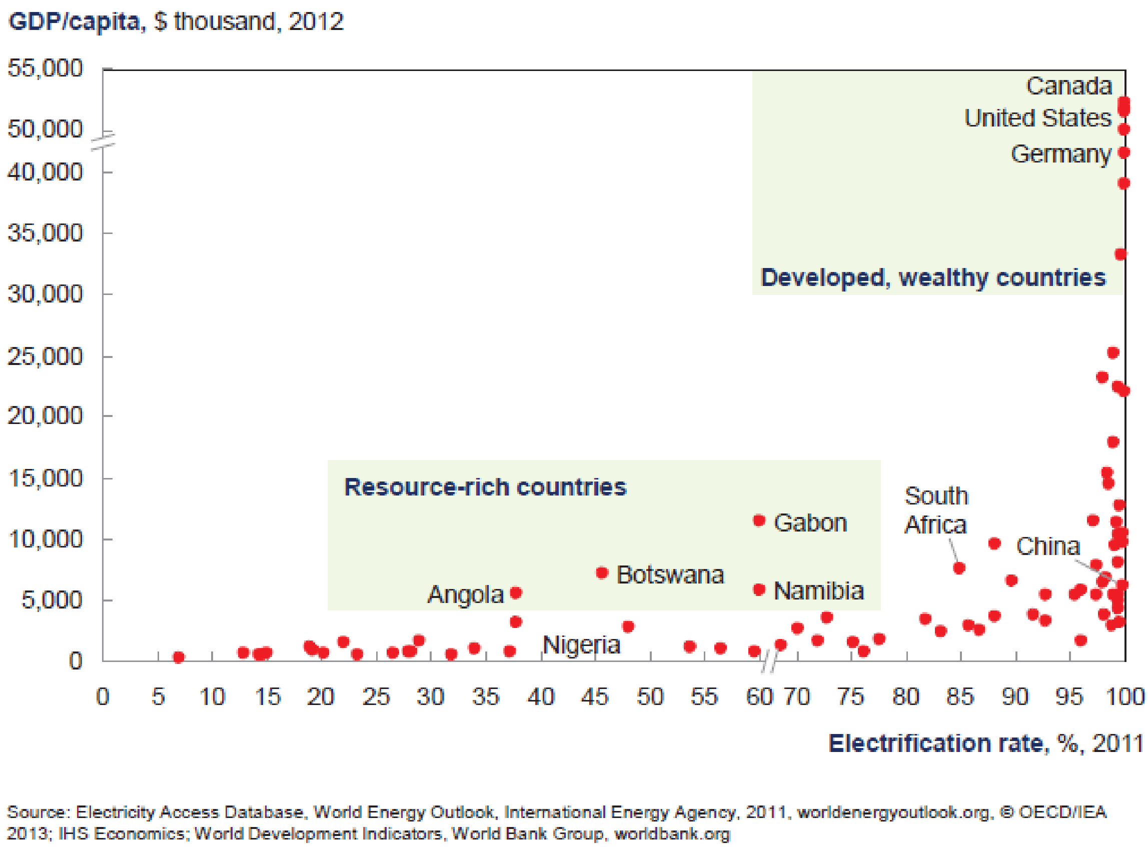
Source: Africa Energy Outlook, IEA, 2019

Unsurprisingly, the electricity that is available in Africa is concentrated in urban areas, where greater density and economic activity levels make the provision of electricity more viable. Even so, in urban areas of Africa, nearly one-quarter of people live without electricity. In contrast, in rural areas across the continent, nearly 70% of people lack electricity access.[xiii]

Indeed, a major demographic consequence of the lack of electricity access in rural areas of Africa is projected population migration to urban areas, where economic opportunities (in significant degree, enabled by electricity supply) are better. As a result, the urban population in SSA could increase by over 500 million people by 2040.[xiv] Since many of the continent's largest cities are already severely stressed on a number of social and environmental dimensions, this migration could further worsen quality of life in African cities – especially if urban energy supply quality is not enhanced.

Unless and until Africa's energy access gap is much more fully addressed, the higher rates of economic activity found in the developed world may be difficult to attain. As exhibited in Figure 1-6, even energy access rates as high as 90% may be insufficient to allow a country to achieve the wealth levels of North America and Europe.

Figure 1-6: High National Per Capita Income Typically Requires >95% Energy Access



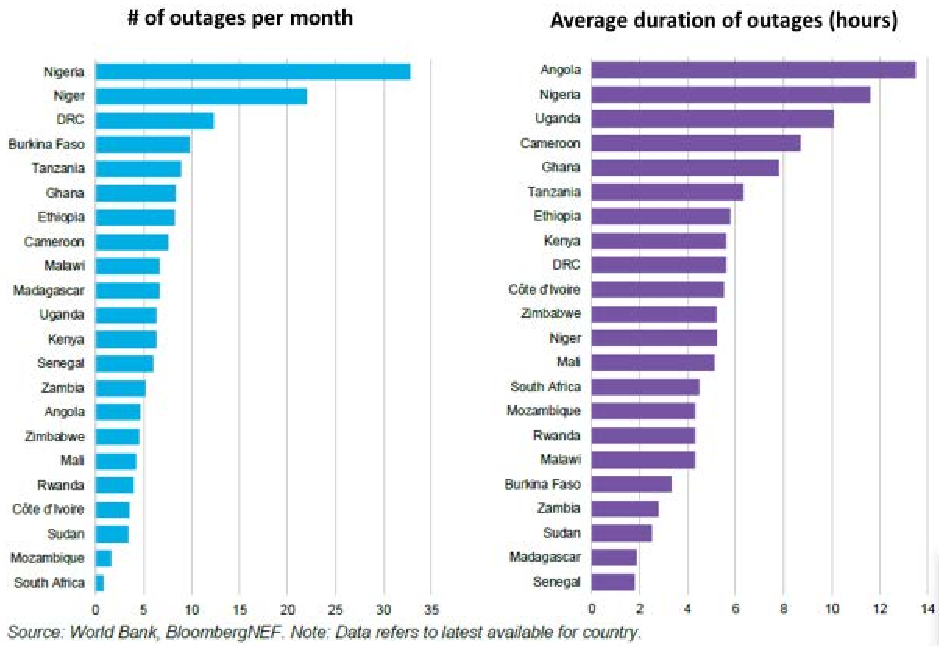
Source: Brighter Africa: The Growth Potential of the Sub-Saharan Electricity Sector, McKinsey & Co, 2015

And, if energy access improvements are achieved in Africa by relying mostly upon fossil fuels, the environmental consequences – particularly climate change – could be highly adverse.

In any event, the entire energy access issue should be considered with care, as energy access statistics can be deceptive in two important ways:

1. "Access" doesn't imply availability of electricity on a 24/7/365 basis. In much of Africa, even where the power grid exists and customers are nominally deemed to have energy "access", electricity is frequently unavailable, usually because demand exceeds supply, leading to blackouts or power rationing. As indicated in Figure 1-7, outages on the local electricity grid are frequent and widespread across much of Africa.

Figure 1-7: African Electricity Customers Subject to Frequent and Prolonged Power Outages



Source: Solar for Businesses in Sub-Saharan Africa, BloombergNEF, 2019

2. "Access" doesn't mean electricity infrastructure capable of producing and delivering quantities of electricity to users at volumes typical of consumption patterns in developed economies. As shown previously, the relationship between per capita income and per capita electricity use is strongly positive – and moreover is highly non-linear.[xv] Reflecting this, virtually nowhere in Africa has "access" to electricity in abundance comparable to North America or Europe, and most Africans connected to the grid subsisting at the most minimal level of access. Figure 1-8 illustrates a taxonomy describing five conceptual tiers of energy access, as defined by the IEA, which is widely considered to be the world's thought-leader on this topic.

Figure 1-8 Five "Tiers" of Energy Access With Increasing Degrees of Electricity Consumption

	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
INDICATIVE SERVICES	Task lighting + phone charging or radio	Tier 1 + General Lighting + air circulation + television	Tier 2 + Light applicances	Tier 3 + Medium or continuous applicances	Tier 4 + Heavy or continuous applicances
1. Peak capacity	3 W	50 W	200 W	800 W	2 Kw
2. Service hours	4 hrs/day	4 hrs/day	8 hrs/day	16 hrs/day	23 hrs/day
3. Reliability				✓	✓
4. Quality				✓	✓
5. Affordability			✓	✓	✓
6. Legality				✓	✓
7. Health/Safety				✓	✓

Source: Derisking Renewable Energy Investment: Off-Grid Electrification, ETH Zurich and UNDP, 2018

> In this taxonomy, entry-level "Tier 1" energy access characteristic of much of Africa means that a customer can only power a light bulb or a radio for a few hours a day. Meanwhile, "Tier 5" access reflects the degree of electricity service typically available in North America or Europe, able to power any combination of heavy-duty appliances at any time. In terms of peak capacity, which is akin to bandwidth for electricity service, Tier 5 access is three orders of magnitude greater – with correspondingly much higher capital costs to provide the necessary generation and delivery capacity – than Tier 1 access.

Thus, a goal of "100% electricity access" effectively means that some kind of power distribution system should exist in every village of a country – but it does not ensure that the electricity from this system is always (or even most of the time) available or that the system could support most households consuming electricity in quantities – or at the lower prices – characteristic of developed economies.

In other words, policymakers often make assumptions that reduce the realistic scope of the energy access problem in Africa, setting the bar extremely low wherein the most minimal level of investments – and minimal corresponding increases in electricity consumption – will suffice.

Even so, just to bring the most basic Tier 1 level of electricity to every African, the gap between current levels of African energy access and the UN SDG7 goal of 100% energy access by 2030 is clearly very large.

It is unclear realistically how quickly such a large gap can be closed – particularly since growth in electricity demand rarely occurs without economic growth already happening too.

Electricity Demand Poised for Growth

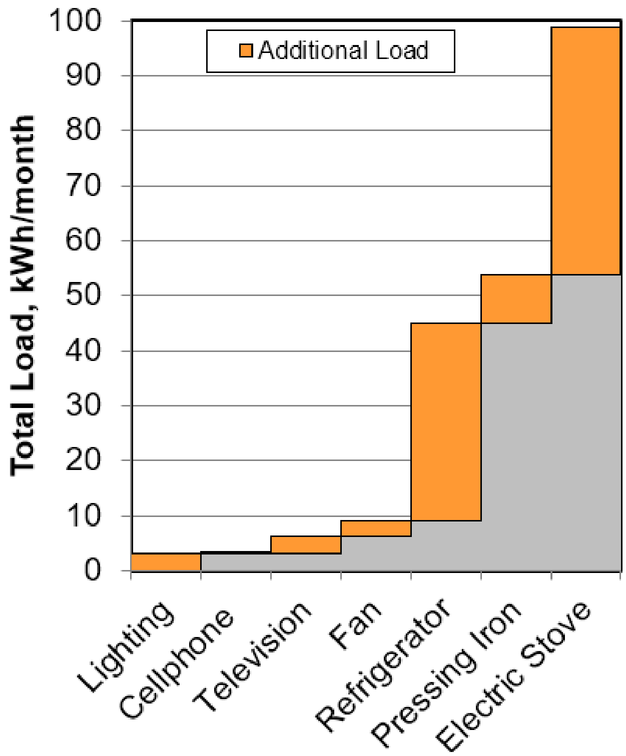
Because electricity demand is usually tied to economic activity and wealth, it is particularly difficult for a viable electricity sector to gain a foothold for sustainable growth where no grid exists and where the population has very limited purchasing power, as is now the case in many parts of SSA.

Before any industry can take root, there first needs to be a meaningful and consistent level of electricity demand. For those living in developed economies, a sizable foundation of demand for electricity is generally taken for granted, wherein everyone alive has always had electric lights, refrigerators, televisions, and (more recently) computers.

In contrast, where there has never been electricity, no-one owns any electricity-consuming devices, and because of low purchasing power, establishing some initial level of electricity demand in a financially sustainable way is challenging.

Figure 1-9 illustrates the initial growth steps of a household's monthly electricity consumption as new appliances are added, indicating how small those first steps can be and the significance of the first major appliances adopted on required expansion of electricity infrastructure.

Figure 1-9: Initial Step Increases in Electricity Consumption as Appliances Are Added After Energy Access Is Brought to New Customers

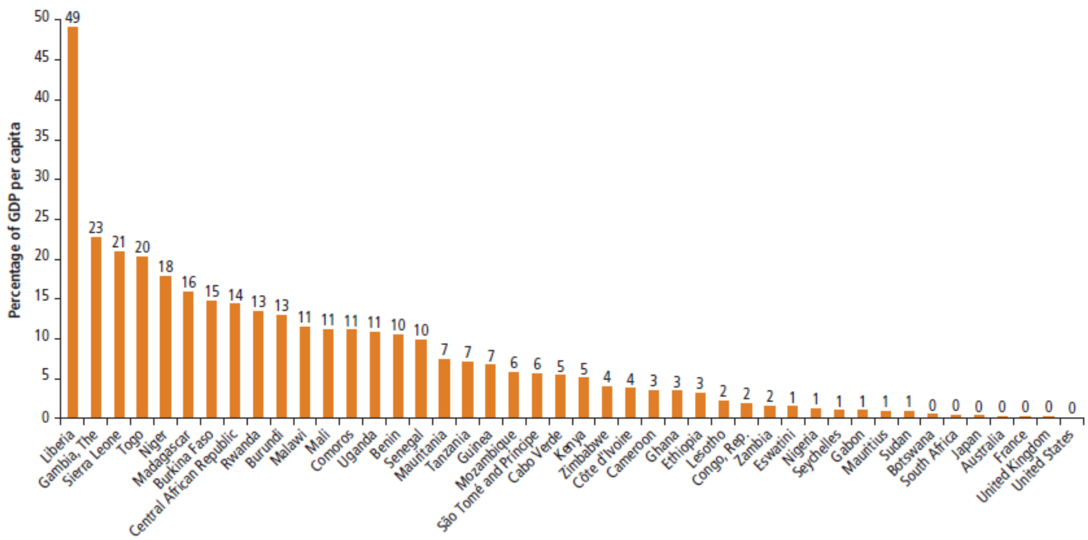


Source: "Assessing Africa's Off-Grid Electricity Demand", Engineers Without Borders, 2019

But even these small initial steps in electricity consumption are economically difficult for many Africans. Given low purchasing power in most African nations, expenditures on electricity consume a relatively high proportion of average household income.

As shown in Figure 1-10, for households in many African nations, more than 10% of income is required to operate a refrigerator. In Liberia, the average household would need to allocate essentially half its income on refrigeration, thus limiting the ability for most to possess perishable foods and medicines.

Figure 1-10: Percent of Average Household Income Required to Power a Refrigerator, By Country

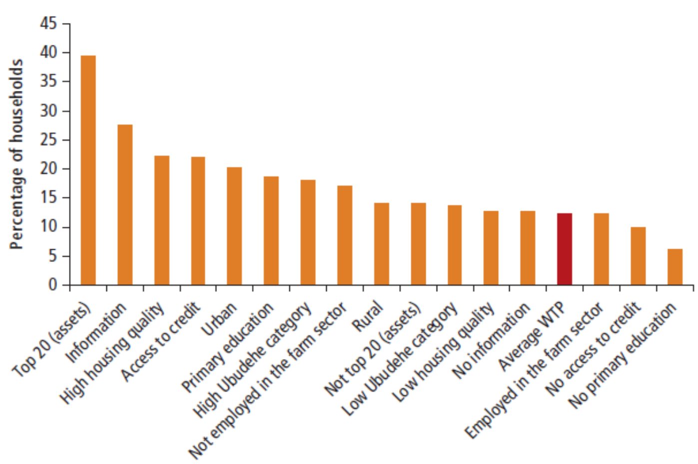


Source: Trimble, Kojima, and Perez Arroyo 2016.
Note: A refrigerator consumes roughly 459 kilowatt hours per year. GDP = gross domestic product.

Source: <u>Electricity Access in Sub-Saharan Africa</u>, World Bank, 2019

Compounding the lack of purchasing power for electricity across Africa is a low indicated willingness to pay for the introduction of electricity services. Figure 1-11 shows that less than 20% of Rwandans are willing to pay for electricity. Even for the wealthiest 20% of Rwandans, not even 40% are willing to part with money for electricity service.

Figure 1-11 Few Households Willing to Pay for Electricity Service in Rwanda



Source: World Bank Multi-Tier Framework data for Rwanda 2017.
Note: Top 20 (assets) refers to the wealthiest 20 percent of households based on an index measuring asset possession. Ubudehe is a term used in Rwanda to classify households in different socioeconomic categories. The higher the category, the more well-off is the household. WTP = willingness to pay.

Source: <u>Electricity Access in Sub-Saharan Africa</u>, World Bank, 2019

The aversion to pay for electricity in Africa is further reflected by the high degree of electricity theft and low degree of electricity bill collection prevalent in many African countries. To provide two illustrations of this phenomenon:

- Eskom, the national utility in RSA, reported that about $350 million worth of electricity was lost to theft in 2015.[xvi]
- The national utility in Liberia (the Liberia Electricity Commission) is reported to lose over 60% of electricity generated to power theft.[xvii]

Moreover, as seen in Figure 1-12, electricity service is not easy to obtain: for those customers in Africa who do want to connect to the electricity grid, new hookups take a very long time.

Figure 1-12: Average Number of Weeks to Complete Electricity Connection in Africa

Sources: Adapted from Blimpo et al. 2018 and based on a survey of selected households that connected to the electric grid within a year of the survey date in 10 African countries.

Source: Electricity Access in Sub-Saharan Africa, World Bank, 2019

For the above reasons, as well as a long legacy of barriers to education and commerce socially embedded during the continent's colonial era, electricity demand growth in Africa has been slow to take off.

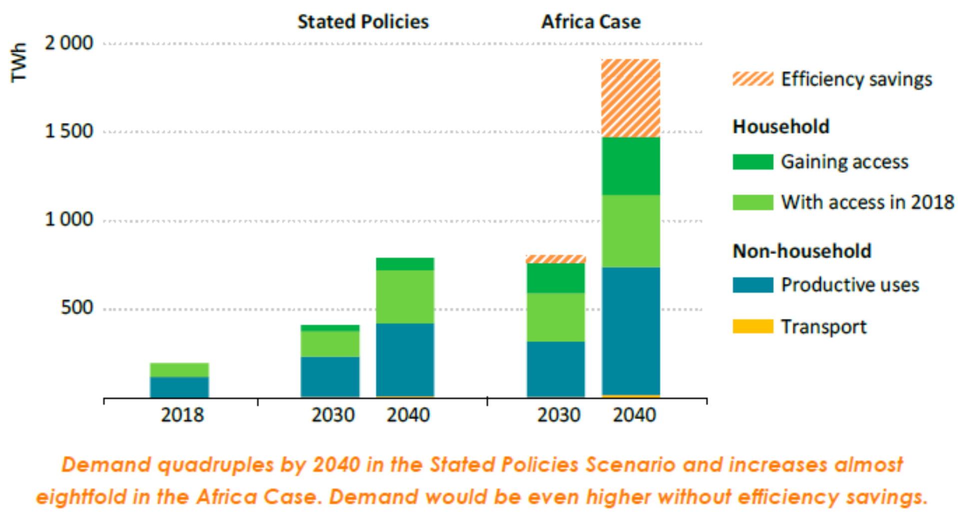
In general, any phenomenon that starts from a small base usually experiences relatively high growth rates until maturity is achieved. At least to date, this hasn't been the case for African electricity consumption: since 2010, African electricity use (as measured by electricity generation levels) increased from 560 TWh to 705 TWh in 2018, or 3% per year – only half the growth rate of developing economies in Asia.[xviii]

Almost certainly, the rate of African electricity consumption growth would likely have been higher if infrastructure had been expanded (or had been able to expand) even faster. Put another way, even though demand-side fundamentals aren't yet strong, growth in the African electricity sector has generally been supply-constrained.

This situation is expected to pertain for many years to come. And, without aggressive action to expand infrastructure even more rapidly, the electricity supply deficit may well worsen: in its most recent assessment, the IEA forecasts electricity consumption growth to be higher in SSA than any other region in the world – in part due to the significant degree of urbanization expected to occur in Africa.[xix]

Figure 1-13 presents IEA's most recent projections of electricity consumption growth in SSA (excluding the Republic of South Africa).

Figure 1-13: IEA Projections of Electricity Consumption Growth in Sub-Saharan Africa (excluding Republic of South Africa)



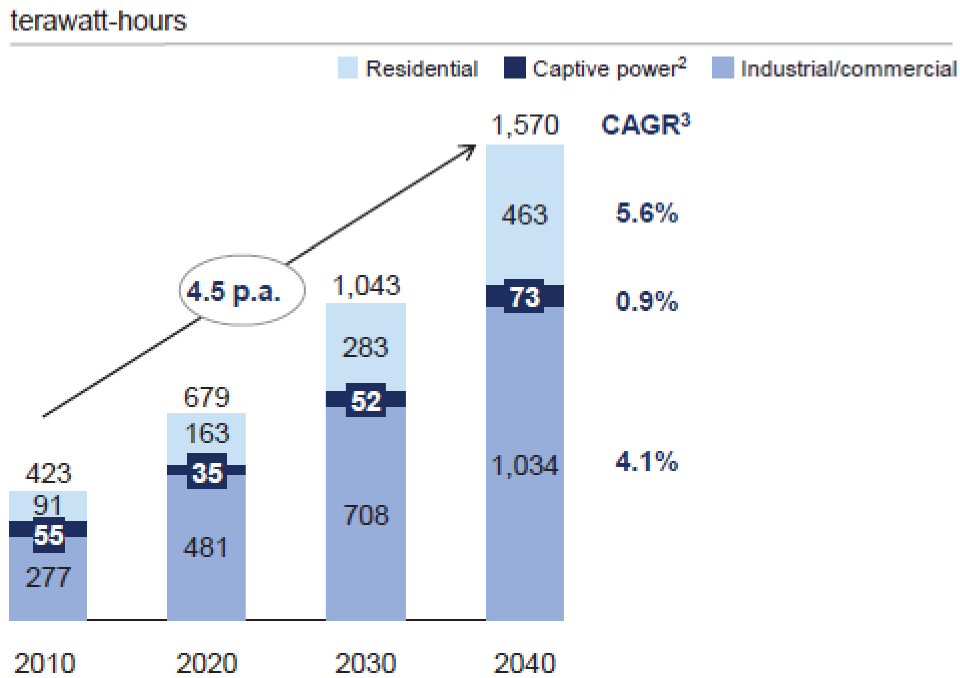
Source: Africa Energy Outlook, IEA, 2019

Even in its more moderate "Stated Policies" case reflecting *status quo* conditions, the IEA forecasts electricity demand to grow at 6.5% year through 2040, to approximately 800 TWh. Moreover, under IEA's more aggressive "Africa Case" reflecting attainment of mid-century economic/social development ambitions that have been established by the African Union, electricity demand growth approaches 10% per year, reaching nearly 1,500 TWh by 2040.[xx]

Electricity consumption growth rates of 6% per year are generally consistent with an outlook recently produced by GEIDCO in which total African electricity consumption reaches approximately six times current levels by 2050.[xxi]

More conservatively, as presented in Figure 1-14, analysis from the consulting firm McKinsey & Company suggests that electricity consumption in SSA will nearly quadruple between 2010 and 2040, growing at 4.5% per year over the next few decades, with residential electricity demand growing at an estimated 5.6% per year.

Figure 1-14: McKinsey Projections of Electricity Consumption Growth in Sub-Saharan Africa



1 Excludes island countries; 2010 reflects actual consumption, whereas 2020, 2030, and 2040 are unconstrained demand forecasts.
2 Industrial/commercial autogeneration and backup power supply.
3 Compound annual growth rate.
Source: *Key World Energy Statistics*, Organisation for Economic Co-operation and Development and the International Energy Agency, 2013, iea.org; World Development Indicators: Non-OECD Energy Statistics, World Bank Group, 2013, worldbank.org; McKinsey Africa Electricity Demand Model

Source: Brighter Africa: The Growth Potential of the Sub-Saharan Electricity Sector, McKinsey & Company, 2015

It is noteworthy that McKinsey's projections are based on increasing the rates of customer grid-connection where (or close to where) the grid already exists, from 34% in 2010 to 71% by 2040. In other words, most forecasted demand growth is not due to bringing electricity to places far removed from the current grid, but rather due to increasing two factors where grid-based electricity is already to some degree available: (1) customer penetration and density and (2) average use per customer.

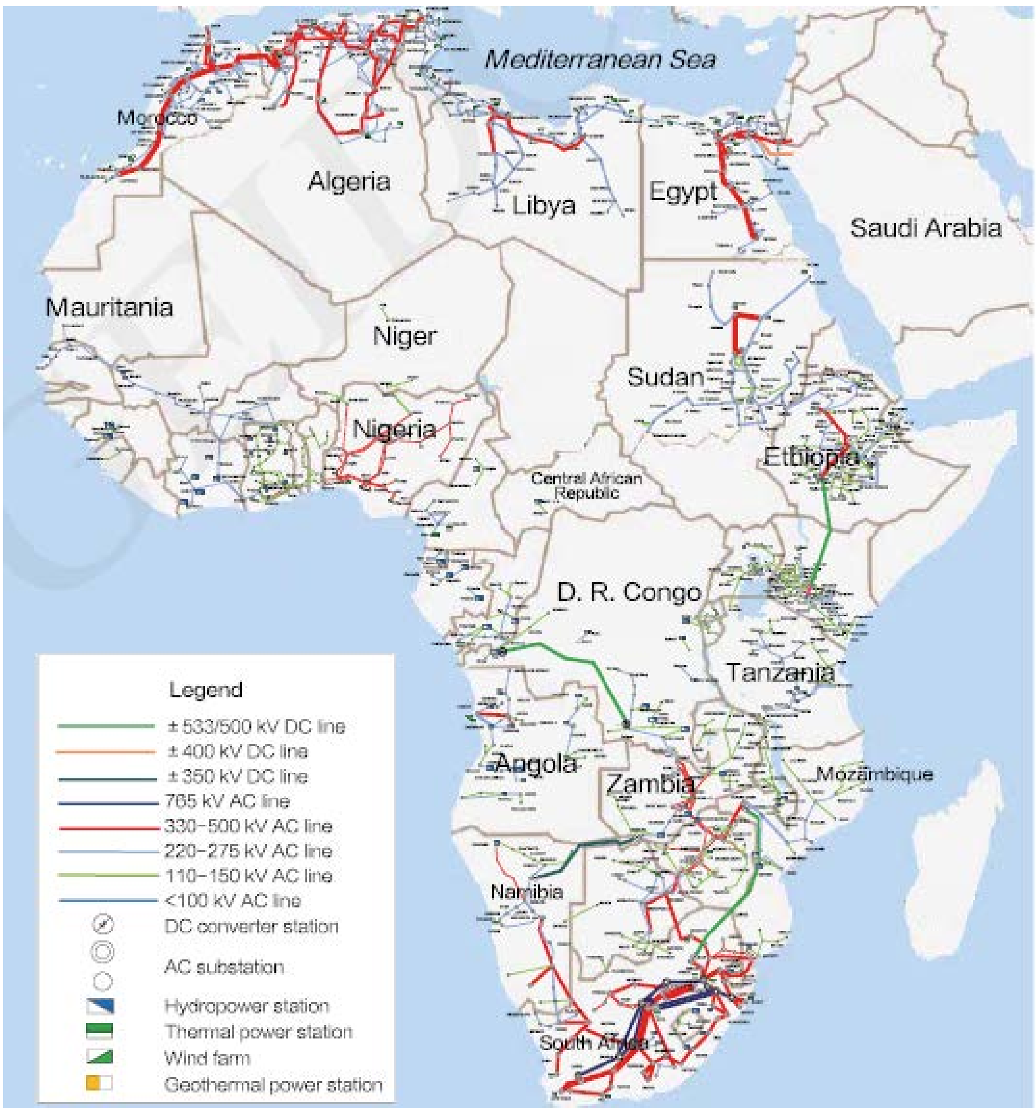
After accounting for another 8% from off-grid connections expected in rural areas, McKinsey estimates that 79% of sub-Saharan Africans are expected to have at least some form of electricity access by 2040. If true, although not meeting UN SDG7, this would nevertheless be a major accomplishment.

Whatever the electricity demand growth rate in Africa turns out to be, the growth rate in electricity supply must be at least as high. The fundamental choices in expanding Africa's electric generating capacity base – fossil vs. renewable, centralized vs. decentralized – are therefore critical.

Insufficiencies in African Electricity Supply

Turning to the supply side of the African electricity equation: the electricity asset base in most African countries consists of relatively few power stations, supplying electricity distribution grids serving only those cities and larger towns with relatively significant economic activity, with power getting from plant to market generally via isolated point-to-point transmission lines. The lack of high-voltage transmission infrastructure in Africa – and especially across most of SSA – is evidenced in Figure 1-15.

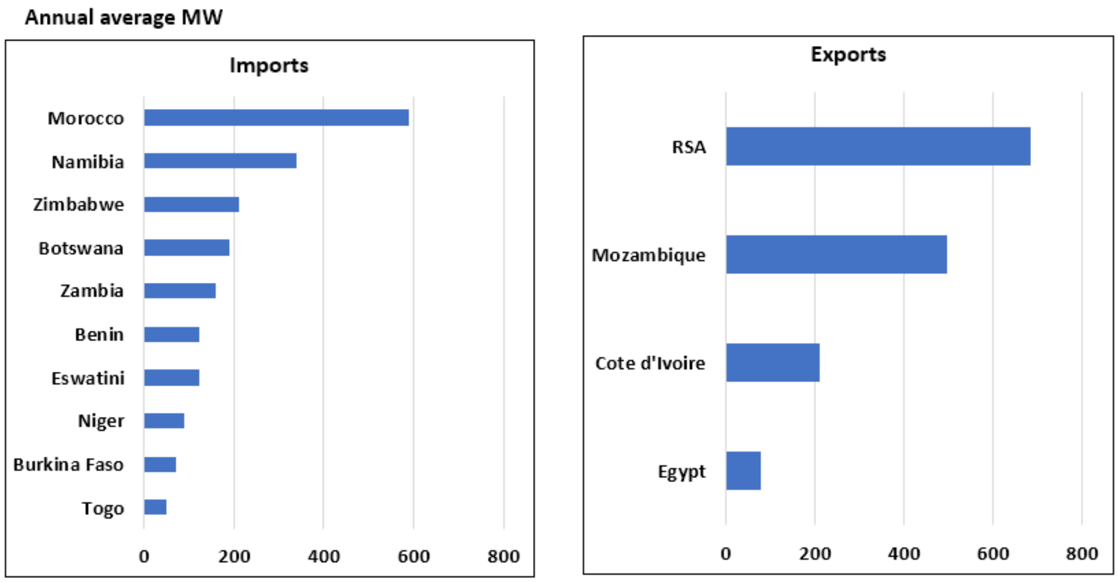
Figure 1-15: Limited Electricity Transmission Network Across Africa



Source: Research on African Energy Interconnection, GEIDCO, 2019

Correspondingly, very little electricity is traded internationally in Africa – not only because of minimal cross-border transmission linkages, but also because most countries have grossly insufficient availability of power to serve their own needs. Figure 1-16 shows that only ten African countries import and four African countries export more than 50 megawatts on an annual-average basis.

Figure 1-16: Largest Power Importers and Exporters in Africa

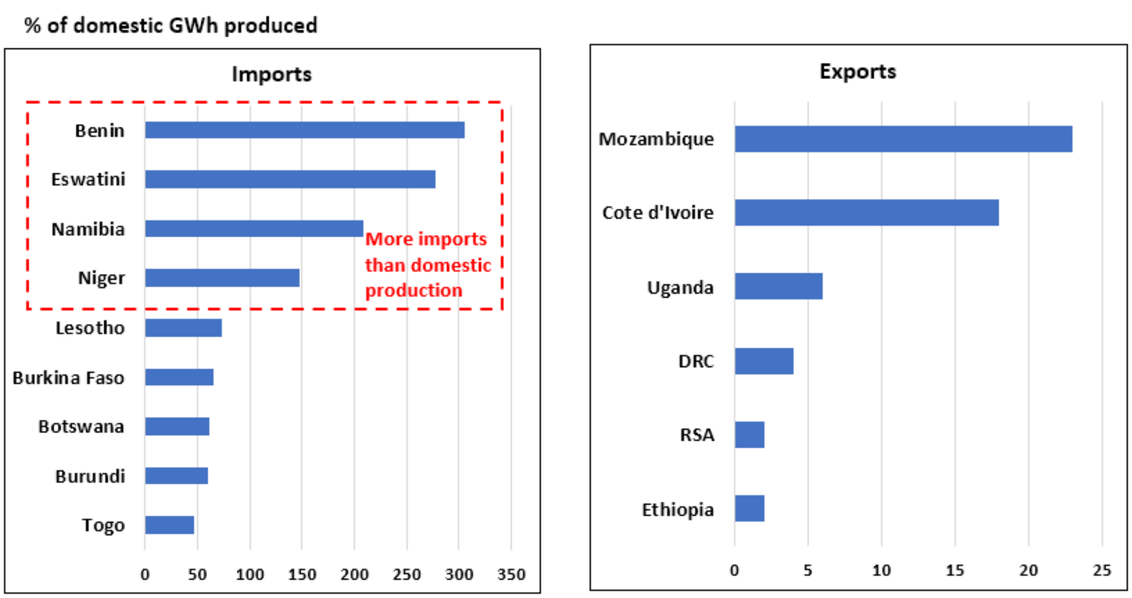


Source: ISE original (based on data from *<u>2016 UN Energy Statistics Yearbook</u>)*

Even though volumes of international electricity transfers in Africa are generally small, this is not to say that all African countries aren't reliant on electricity trade. In fact, a few countries depend critically on cross-national electricity transactions.

As shown in Figure 1-17, four countries (Benin, Eswatini, Namibia and Niger) import more electricity than they produce domestically, and two countries (Mozambique and Cote d'Ivoire) export at least 15% of their electricity production.

Figure 1-17: African Nations Most Reliant on Power Imports and Exports



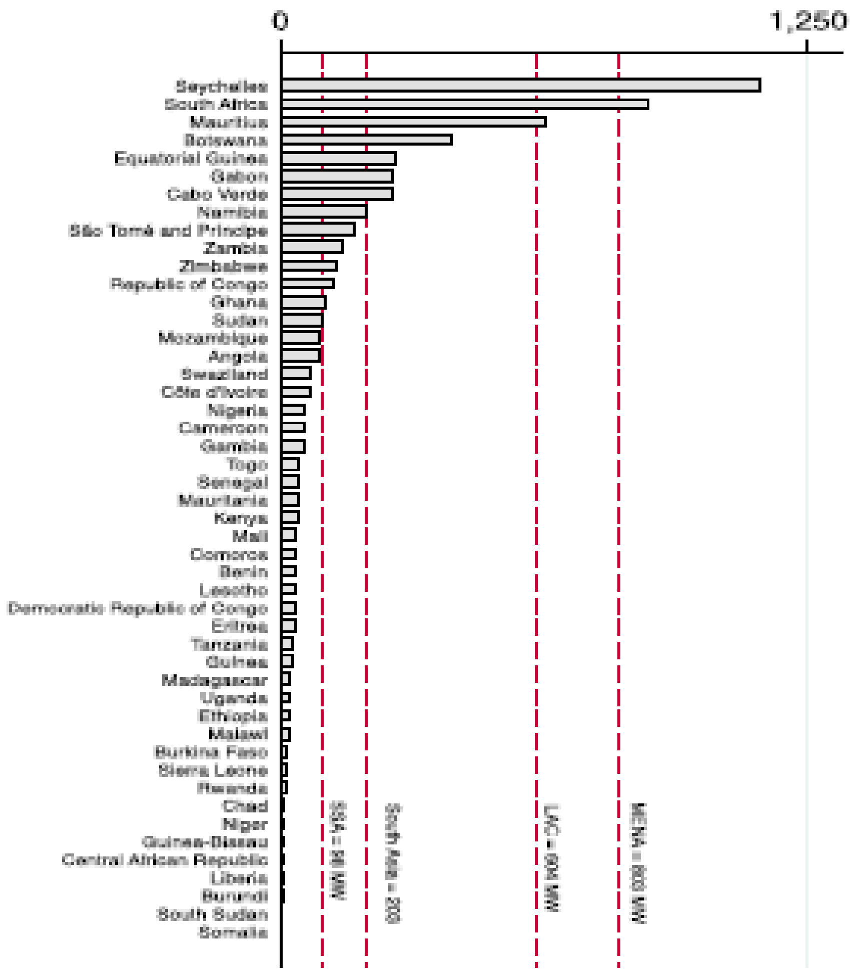
Source: ISE original (based on data from *<u>2016 UN Energy Statistics Yearbook</u>)*

In many cases, the international flows of electricity in Africa that do occur are associated with large industrial facilities served by dedicated long-distance transmission lines: enabling supply from low-cost generation based in another country, or export of generation excess to the local host industry's needs.

While it may seem paradoxical that many African nations depend a lot on electricity trade even though electricity trade volumes are small, this is because African electricity systems – both the transmission system and the power generation base – never attained the extent and robustness of the electricity systems found (and now taken for granted) in North America and Europe. Due to persistent economic stagnation and high degrees of financial risk across Africa, global capital markets have only irregularly financed expansion of the African electricity infrastructure over the past several decades.

On a per capita basis, Figure 1-18 demonstrates that the per capita magnitude of installed grid-based generation capacity in most African countries is far below levels found on other continents.

Figure 1-18: Megawatts of Installed Electric Generating Capacity Per Million People, By Country



Source: Trimble et al., "Financial Viability of Electricity Sectors," 2015, 85–86. LAC refers to Latin America and Caribbean and MENA refers to the Middle East and North America.

Source: "Low Electricity Supply in Sub-Saharan Africa: Causes, Implications and Remedies", Journal of International Commerce and Economics, US International Trade Commission, 2018

As shown in Figure 1-19, the installed base of electrical generating capacity in Africa totaled approximately 236 GW by 2018, having grown from 145 GW since 2010 at 6% per year – twice the rate of growth in recent electricity consumption, reinforcing the notion that demand growth can only follow (and not lead) supply growth.

Figure 1-19: Recent Growth in African Electricity Generation Base (in Megawatts)

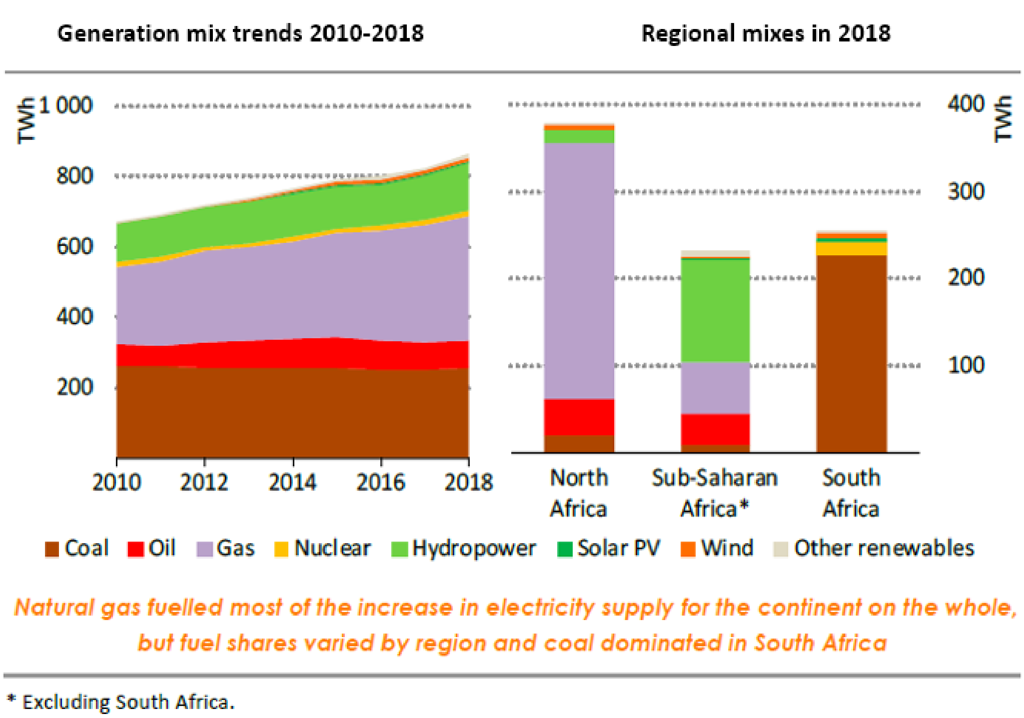
	2010	2011	2012	2013	2014	2015	2016	2017	2018*
North Africa	57,668	61,303	64,242	66,858	71,037	78,383	83,355	90,444	107,410
West Africa	17,535	18,081	19,405	21,512	22,387	24,669	26,514	27,800	31,211
Central Africa	5,007	5,125	5,421	5,990	6,018	6,145	6,162	6,281	6,935
East Africa	9,864	10,599	11,389	11,765	12,418	13,426	15,344	15,733	17,199
Southern Africa	54,791	55,110	56,001	56,616	59,104	61,405	65,205	70,523	73,480
Africa	144,865	150,217	156,458	162,740	170,964	184,028	196,580	210,782	236,235

Source: African Energy Live Data

Source: African Energy Data Book, African Energy Live, 2018

Meanwhile, Figure 1-20 presents the mix of electricity generation sources in Africa.

Figure 1-20: African Electricity Generation Mix



Source: Africa Energy Outlook, IEA, 2019

In Figure 1-20, the IEA depicts the African electricity generation mix in three distinct regions:

- North Africa, representing almost half of African electricity capacity (and where most recent growth has occurred); dominated by natural gas
- The Republic of South Africa (RSA), experiencing minimal growth, now accounting for nearly one-third of Africa's capacity; dominated by coal
- The rest of SSA, less than 20% of Africa's capacity; mostly from hydro

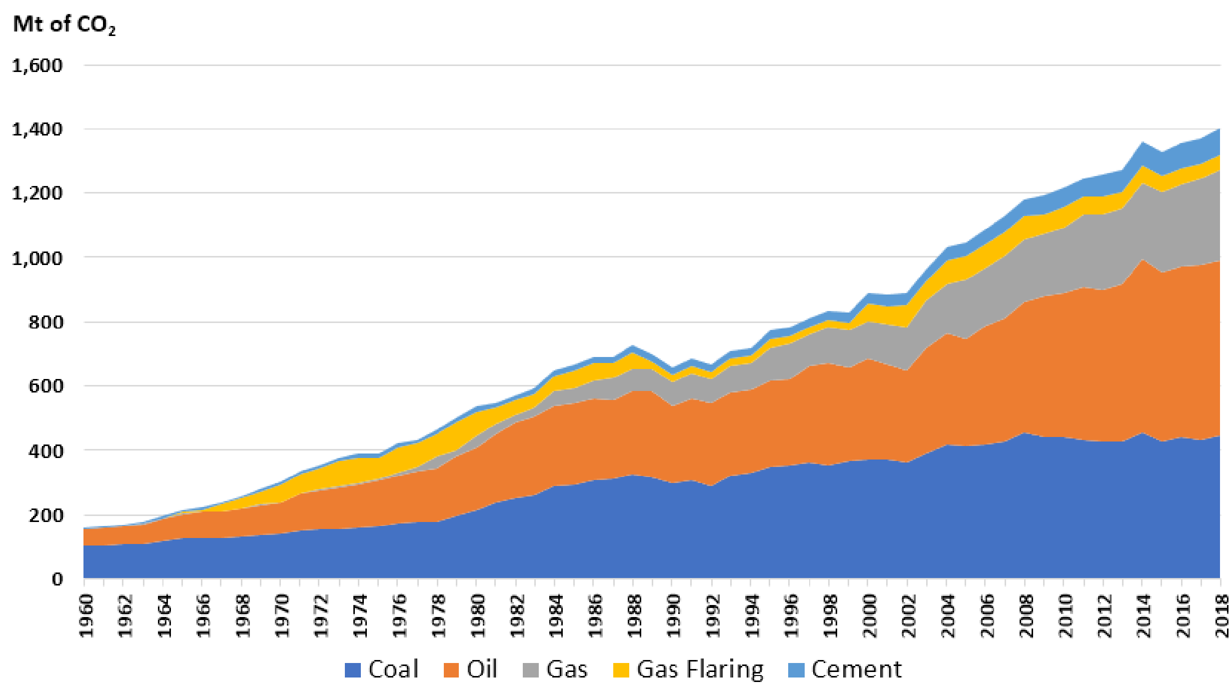
Across the entire continent of Africa, fossil fuels – coal (40%), natural gas (30%) and oil (9%) – account for nearly 80% of electricity production, with hydropower contributing 16%, and tiny shares for nuclear and other renewables. Virtually all recent growth in African electricity generation can be attributed to natural gas, and most of that has occurred in North Africa.

Given the dominance of fossil fuels in the generation mix, as the electricity sector has expanded in recent decades, so too have Africa's CO_2 emissions – the primary contributing factor to climate change.

From a global and historical perspective, because of its relatively low economic advancement and industrial activity over the course of humankind's fossil fuel era, Africa has been responsible for only 3% of total anthropogenic CO_2 emissions cumulatively to date, despite being home to approximately 17% of the world's population.[xxii] This fact makes it problematic to press African stakeholders to take disproportionate steps to mitigate the future trajectory of CO_2 emissions.

Notwithstanding these caveats, it is important to note that CO_2 emissions from the African electricity sector have nevertheless risen substantially in more recent decades, increasing by nearly a factor of ten (or almost 4% annual compounded growth) in the past 60 years, as presented in Figure 1-21.

Figure 1-21: Growth in African CO_2 Emissions Since 1960



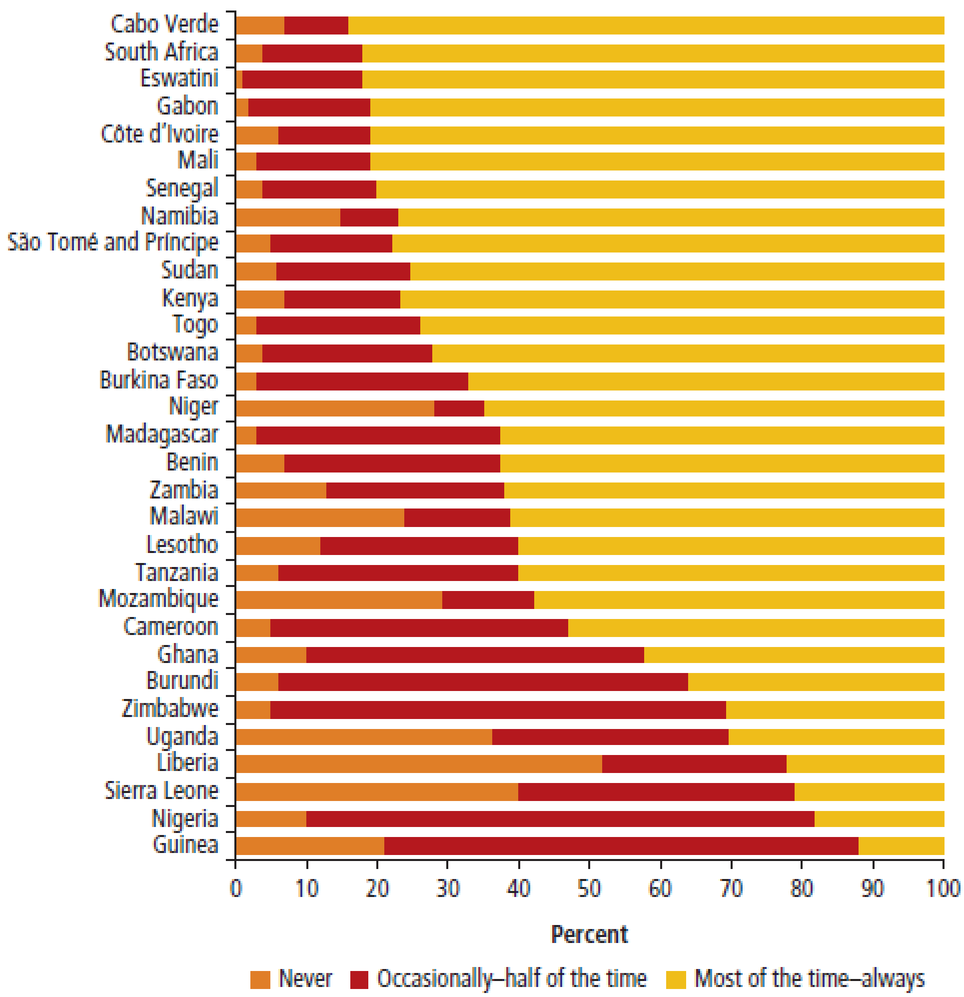
Source: ISE original (data from Global Carbon Atlas website)

Given the supply-constrained nature of the African electricity sector, as it expands in coming decades to meet demand growth, rapid cessation of fossil fuel burn for electricity generation in Africa is unlikely – without which, significant declines in CO_2 emissions are also unlikely.

Not only is the quantity of electric generating capacity inadequate in most African countries, but a sizable share of installed capacity is often unavailable to produce electricity, because of old age compounded by insufficient maintenance. As an extreme example, according to BloombergNEF, roughly half of all the generating capacity in Burkina Faso was off-line in 2017.[xxiii]

Thus, most African power generation assets that can operate, do operate. With minimal operating reserves on the grid, when one power plant goes down, the whole grid often does too. As a result, most African nations suffer from high outage rates, during which electricity is not available from the grid, as seen in Figure 1-22.

Figure 1-22: Availability of Electricity at Grid-Connected Households in African Nations

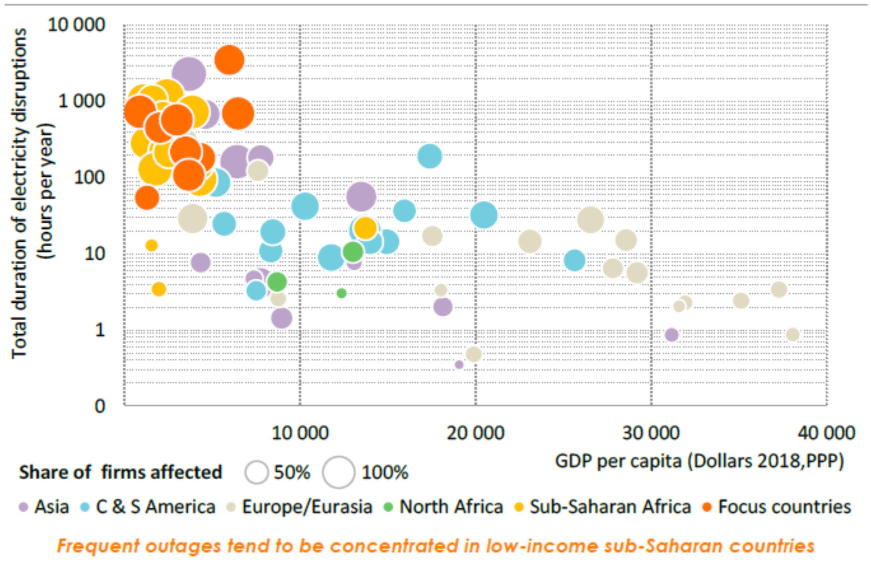


Source: Afrobarometer data 2014/15.

Source: Electricity Access in Sub-Saharan Africa, World Bank, 2019

Africa's poor electricity reliability is undoubtedly a major factor in the continent's lack of economic progress relative to other regions, as is suggested by Figure 1-23.

Figure 1-23: Electricity Outages and GDP Per Capita in Selected Regions, 2017



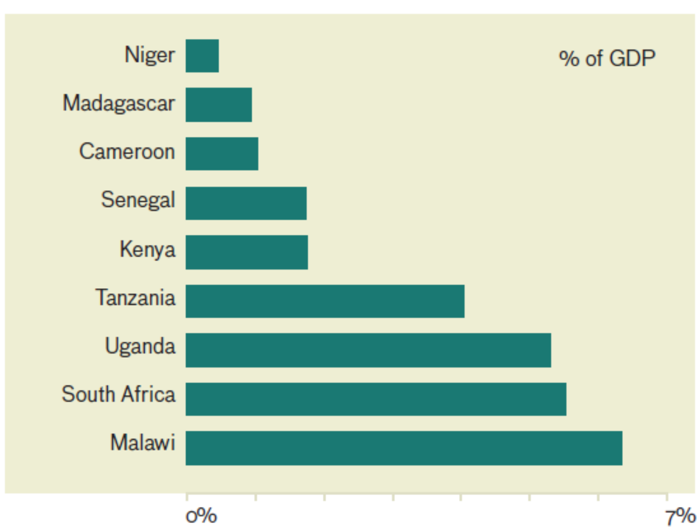
Notes: C & S = Central and South America. PPP = purchasing power parity. Focus countries are Angola, Côte d'Ivoire, DR Congo, Ethiopia, Ghana, Kenya, Mozambique, Nigeria, Senegal and Tanzania.

Source: IEA analysis based on World Bank (2019a).

Source: Africa Energy Outlook, IEA, 2019

As depicted in Figure 1-24, the World Bank estimates that electricity grid outages in Africa impose a cost equivalent to a significant fraction of national economic activity.

Figure 1-24: Economy-Wide Costs Due to Power Outages in Selected African Nations



Source: World Bank

Source: Think Outside the Grid: Africa's Trillion Dollar Energy Opportunity, DBL Partners, 2018

To compensate for high grid outage rates, many African businesses and households with above-average financial means rely on backup power supplies, typically involving diesel generators, solar panels, and/or batteries.

For the most part, official electricity statistics overlook this segment of activity, but by all accounts, self-produced electricity is a very significant factor in African electricity usage – especially for large industrial operations in remote areas (e.g., mining), where isolated grids not connected to the primary national grid are often utilized.

According to the International Finance Corporation (IFC), “the installed capacity of back-up generators is greater than the capacity of power plants connected to the grid” in more than half of the countries in SSA. In West Africa, customer-sited generators produce an amount equivalent to about 40% of all electricity supplied over the grid, and more is spent on fueling generators than operating and maintaining the grid. Reliance on back-up generators is especially pronounced in Nigeria, where an estimated 15-20 GW of backup generators far exceeds grid-connected power plant capacity. Not only are backup generators a major factor in African electricity supply, but also in African fuel consumption, accounting for approximately 20% of all diesel/gasoline burned in SSA. Backup generators are also a major contributor to local air and noise pollution in cities and villages across Africa.[xxiv]

This extensive degree of customer reliance on backup generators reinforces how significant the grid-based electricity supply deficit is across Africa. Expanding the existing base of African electricity infrastructure – both grids and generation assets – might gradually displace carbon-intensive and locally-polluting backup generation.

However, the effectiveness of building more large-scale generation assets in Africa to supply more power will be impeded if there is insufficient interregional integration of the electricity grids that already exist.

Role and Opportunity for Power Pools in Africa

As the electricity sector developed in other parts of the world during the 20th Century, economic efficiencies dictated the creation of grid interconnections to make the most cost-effective use of new and increasingly large increments of electric generating capacity additions. Accordingly, in most developed economies, “power pools” were established to link grids and jointly capture economies of scale in electricity generation.

In its formative years, Africa’s electricity sector was developed on a local level, wherein a grid of modest extent was constructed to serve a certain city or industrial facility. Lacking interregional transmission ties, power pools were effectively a moot concept for Africa. It has only been during the past thirty years, due to growing regional economic collaborations among African nations, that power pools have begun to emerge. Today, five interconnected power pools span the continent, summarized in Figure 1-25.

Figure 1-25: Power Pools in Africa

Power Pool	Countries	Founded in
Comité Maghrébin de l'Electricité (COMELEC)	Algeria, Libya, Mauritania, Morocco and Tunisia	1989
West African Power Pool (WAPP)	Benin, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo	2000
Central African Power Pool (CAPP)	Angola, Burundi, Cameroon, Central Africa Republic, Chad, Congo, DRC, Equatorial Guinea, Gabon, Sao Tome and Principe	2003
Eastern Africa Power Pool (EAPP)	Burundi, Democratic Republic of Congo (DRC), Djibouti, Egypt, Ethiopia, Kenya, Libya Rwanda, South Sudan, Sudan, Tanzania and Uganda	2005
Southern African Power Pool (SAPP)	Angola, Botswana, Democratic Republic of Congo (DRC), Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe	1995

Source: *UNEP 2017: 61*

Source: African Power Pools: Regional Energy, National Power, ECDPM, 2019

Albeit at different stages of development and with different sets of policies for inter-country commerce, the five African power pools were formed primarily to create economic viability for large centralized power generation projects (hydroelectric facilities often exceeding a GW), and secondarily to enable trading of power across national boundaries when different countries have surpluses and deficits of electricity generation.

In the relatively few years in which they have existed, the power pools have notched some successes in joint planning of large-scale generation assets and supporting transmission projects, and in providing assistance to member countries on feasibility studies and other steps during the development process.

Although difficult to quantify, the power pools have improved electricity resilience at the bulk power level so that distribution companies and larger commercial/industrial (C&I) customers have somewhat better access to regional electricity supplies at lower-cost and higher-reliability than could be achieved domestically. The improved ability for large C&I customers in remote areas (such as mining operations) to effectively source power has been of particular benefit to local communities that would otherwise not have (at least to date) gained energy access by national utility expansion plans alone.

Unfortunately, in practice, the five African power pools are unable to offer many of the economic advantages of scale in electricity supply as observed in power pools in developed economies such as in North America and Europe. This is because, as discussed previously, there is proportionally less opportunity for cross-border trade in electricity in Africa, for two reasons:

- Most regions are chronically short of generation; any regional generation surpluses are infrequent and small
- International transmission interconnections are weak, often limiting the ability to export power

In the view of BloombergNEF, the most advanced power pool in Africa is the Southern African Power Pool (SAPP), within which RSA's giant national utility Eskom is the critical player. Created in 1995, SAPP launched a short-term electricity trading platform in 2001, followed by a competitive day-ahead market in 2009, and then an intraday market in 2016. As of 2017, roughly 6 TWh of energy was transacted between SAPP counterparties, of which about 14% was via these competitive markets.[xxv]

Since they are focused solely on planning and operations of the high-voltage network, the African power pools pay limited attention on the lower-voltage activity of electricity distribution, which is the lynchpin of residential electricity access.

For this reason, and because they lack authority to enforce targets if member sovereign nations fail to comply, the African power pools have not established electricity expansion goals. The regional power pools and their system planners should theoretically account for nationally-set aspirations when developing resource expansion plans. Even so, it is unclear to what degree energy access is considered in planning, as the power pools are generally still young and thus still maturing in their planning resources and capabilities.

Projected Additions to Electricity Supply and Growth in CO_2 Emissions

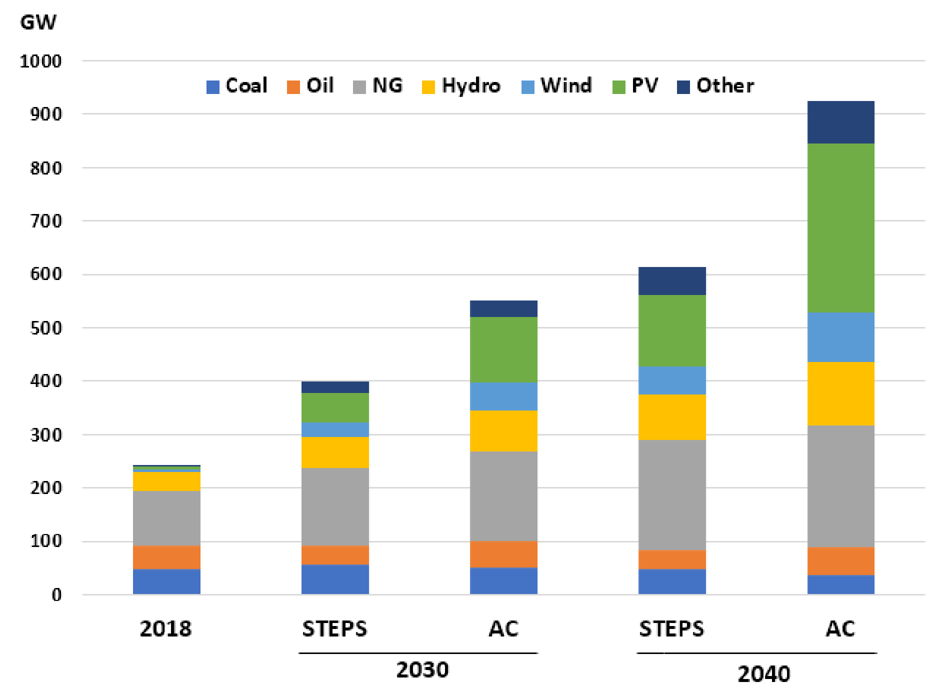
In its recent analysis of the African energy sector, Africa Energy Outlook 2019, the IEA developed two scenarios of future growth:

- Stated Policies Scenario ("STEPS"), which reflects projected continuation of "policy frameworks and plans" that are currently in place today across Africa.
- Africa Case Scenario ("AC"), which reflects achievement of the Africa Union's 2063 Vision including (among other things) universal energy access.

Thus, IEA's STEPS scenario is effectively a base case representing continuation of the *status quo*, whereas the AC scenario reflects more aggressive pursuit of a greater degree of ambition in African electricity sector advancement.

From a generating capacity standpoint, IEA's forecasts indicate that installed capacity in 2040 could reach 614 GW under the STEPS scenario and 924 GW under the AC scenario, as shown in Figure 1-26. This would reflect an addition of 370-680 GW of new power generation from today's levels, with the biggest share of this growth contributed by solar PV. In addition to dramatic growth from PV, other renewables (especially hydro and wind) and natural gas also are projected to experience significant increases in capacity, whereas capacity fueled by coal or oil remains effectively constant.

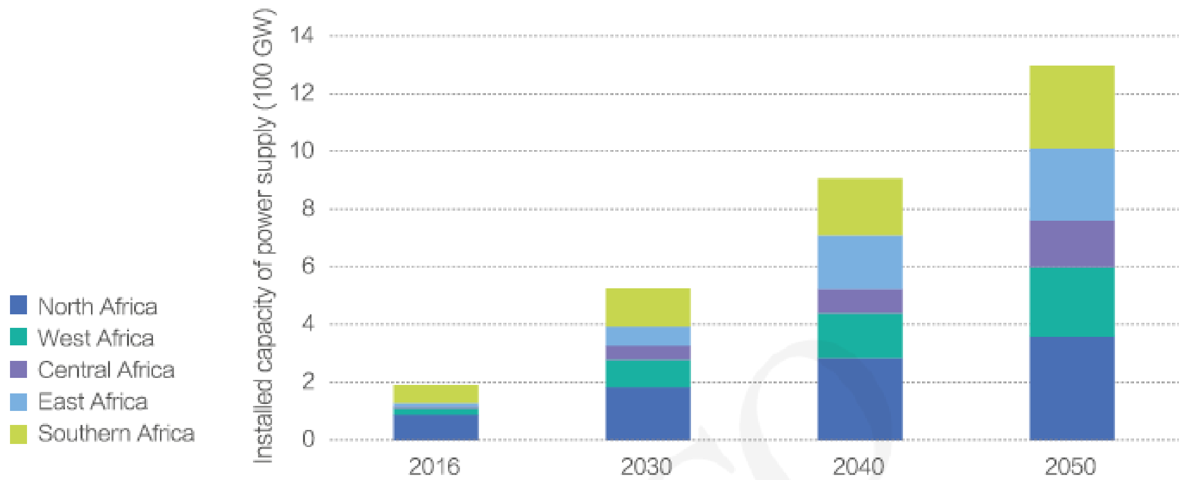
Figure 1-26: IEA Projections of Future Growth in African Power Generation Capacity



Source: Africa Energy Outlook, IEA, 2019

For comparative purposes, GEIDCO's recent analysis of future African electricity sector capacity expansion (shown in Figure 1-27) is intermediate between the two IEA scenarios, estimating roughly 850 GW of installed capacity in Africa by 2040, *en route* to about 1300 GW by 2050.

Figure 1-27: GEIDCO Projections of Future Growth in African Power Generation Capacity

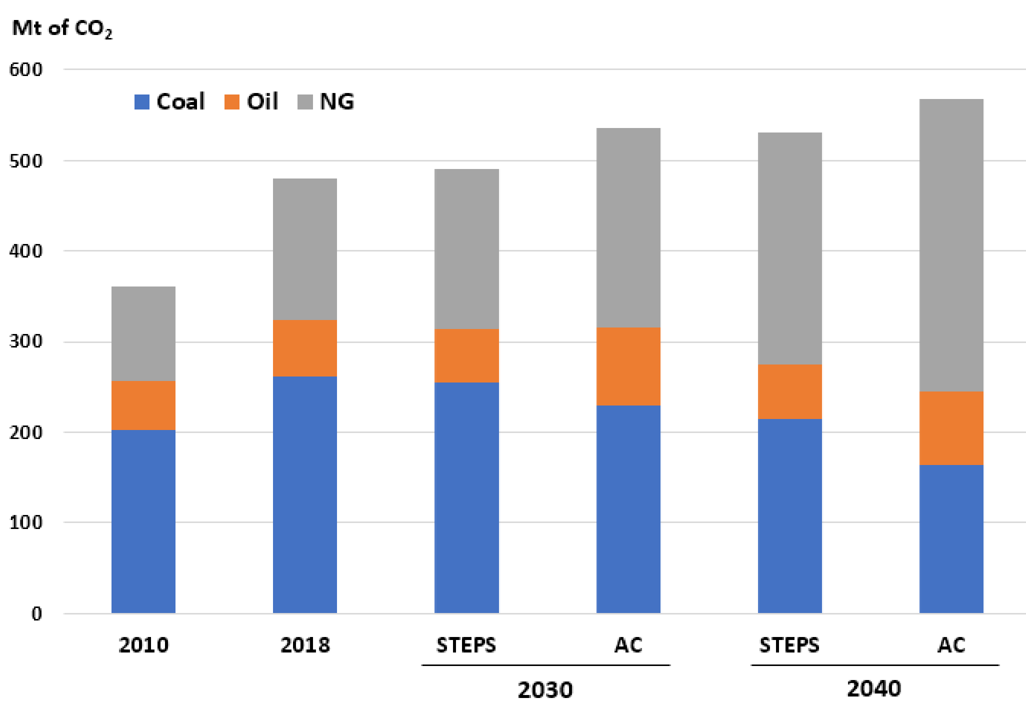


Source: Research on African Energy Interconnection, GEIDCO, 2019

Notwithstanding the increasing share of electricity generation to be provided by renewable energy sources, CO_2 emissions from the African electricity sector are generally expected to continue to increase.

In IEA's scenarios, CO_2 emissions from the African electricity sector is forecasted to increase by 10-20% between now and 2040. As depicted in Figure 1-28, most of the growth in CO_2 emissions can be attributed to anticipated expansion in natural gas electricity generation.

Figure 1-28: Projected Growth in CO_2 Emissions from African Electricity Generation



Source: Africa Energy Outlook, IEA, 2019

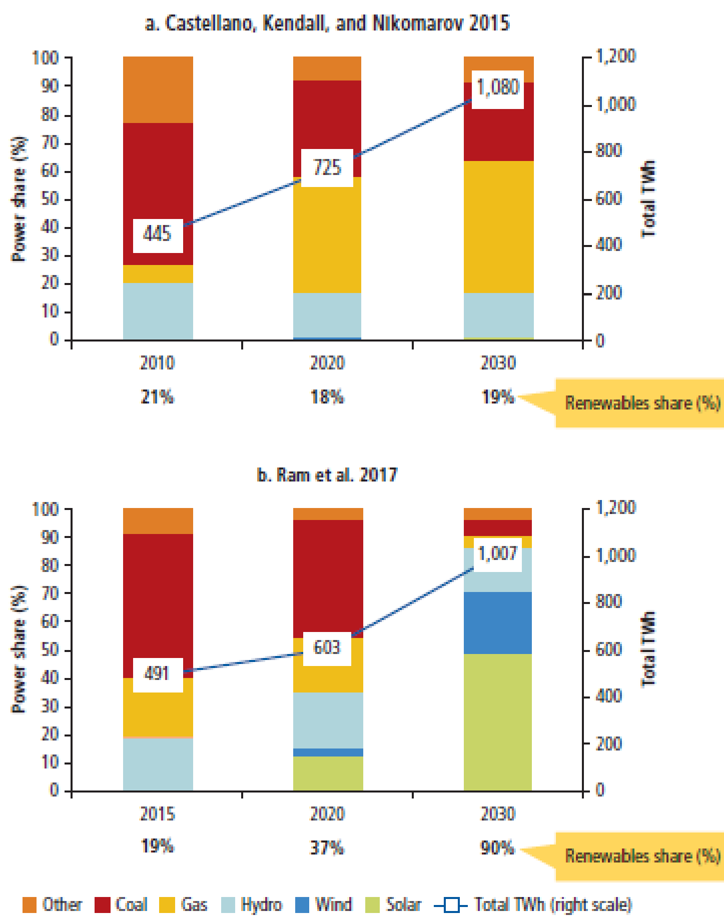
However, it should be noted that IEA's CO_2 emission forecasts reflect the assumption that a significant quantity of African coal-fired generation retires during the forecast horizon. This assumption is questionable given how capacity-short the African electricity sector is and will remain for the foreseeable future. If the assumption of declining coal-fired generation turns out to be incorrect, through a combination of increased construction and deferred retirements, the rate of growth in African electricity CO_2 emissions could be somewhat higher than IEA forecasts.

Generation Mix: The Swing Factor for Future CO_2 Emissions in Africa

For CO_2 emissions from the African electricity sector to remain flat (much less decline), it will be critical to ensure that as much new renewable energy infrastructure be introduced as quickly as possible.

How quickly and to what degree the expansion of renewable energy can be achieved in the African electricity sector is an open – and vitally important – question.

Figure 1-29: Two Recent Analyses Exhibit Major Differences in Projected Future African Electricity Generation Mix



Sources: Adapted from Castellano, Kendall, and Nikomarov 2015 and Ram et al. 2017.
Note: Other includes bioenergy, geothermal, oil, and nuclear. TWh = terawatt hours.

Source: Electricity Access in Sub-Saharan Africa, World Bank, 2019

With renewable energy alternatives much more cost-effective than they were even a few years ago, perspectives on the future mix of generation additions in Africa have been in flux. To illustrate this, Figure 1-29 summarizes two very different forecasts of African electricity generation through 2030 that were developed only two years apart (2015 and 2017).

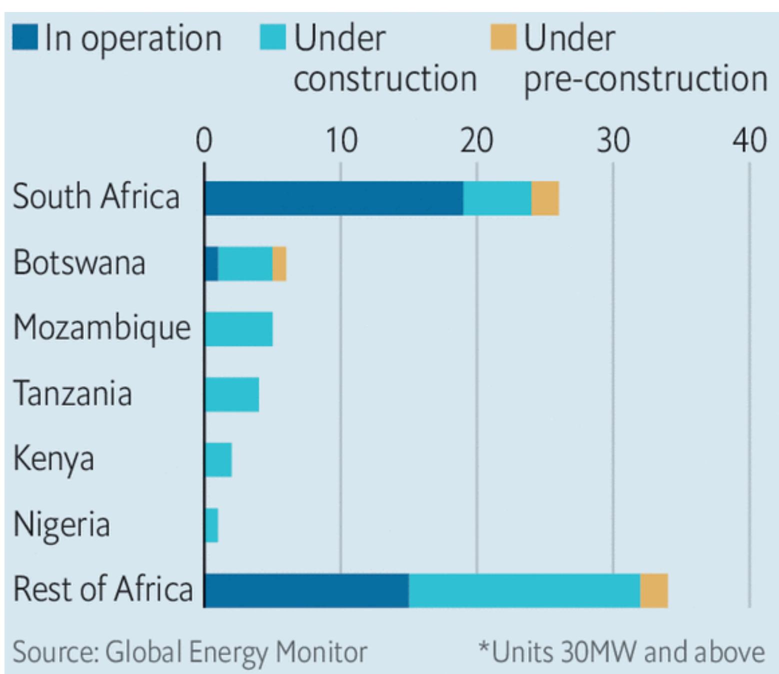
At the aggregate level, there is good agreement between the two studies shown in Figure 1-29 on the absolute amount of electricity generation (1,000 TWh) to be added in Africa by 2030. However, the first analysis indicates that renewables will account for less than 20% of generation by 2030, whereas the second analysis suggests a 90% share of generation from renewables by 2030. Notably, solar and wind account for virtually none of 2030 generation in Africa in the first analysis, and roughly two-thirds of 2030 generation in Africa in the second analysis.

Clearly, the implications of this difference on the future trajectory of emissions from the African electricity sector are enormous.

In addition to maximizing renewable energy deployment, arguably the most important remaining swing factor driving the future trajectory of CO_2 emissions from the African electricity sector will be the degree of reliance on coal-fired power generation, relative to alternatives.

Across Africa, there is 48 GW of coal-fired capacity, and RSA is home to 85% of it. While dominating the electricity industry in RSA, coal is otherwise not a significant factor in the electric generating base elsewhere in Africa, with only minor contributions in a dozen countries.[xxvi] Yet, several other countries are now building or planning deployment of their first coal power plants, as seen in Figure 1-30.

Figure 1-30: Number of Coal-Fired Power Plants in Selected African Nations (as of July 2019)



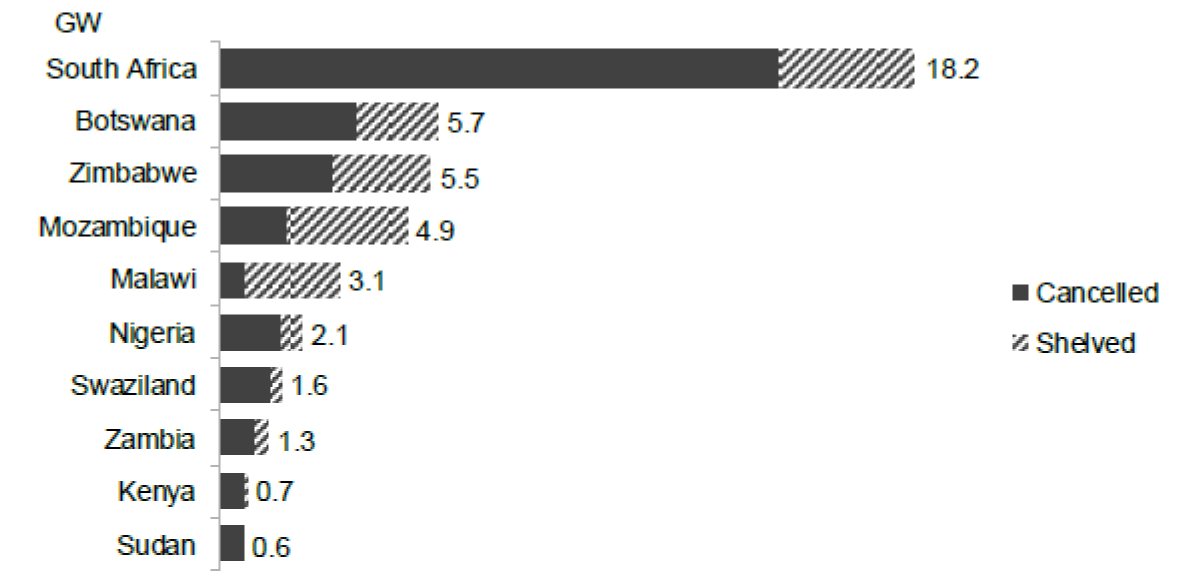
Source: "African Countries Plan to Build Dozens of Coal-Fired Power Stations", The Economist, July 25, 2019

It is unclear how many of these new coal plants being planned or constructed will actually come on-line, not only because of the challenges in completing major capital projects in Africa (discussed further below), but also because of the general global trends against coal-fired electricity.

In many countries around the world, existing coal power plants are being closed and new coal power plants under development are being cancelled at an accelerating rate, due to deteriorating relative economics and increased risks of stranding new investments if/as decarbonization policies or mandates drive coal-fired generation out of the market. Indeed, a growing number of financial institutions serving the global infrastructure marketplace are ceasing lending activity to new coal projects.[xxvii]

Across SSA, over 30 GW of proposed coal-fired additions – mostly in RSA – have already been cancelled or shelved in recent years, as shown in Figure 1-31.

Figure 1-31: Coal Power Plant Capacity Shelved or Cancelled



Source: Global Energy Monitor, BloombergNEF. Note: Refers to 2010-19 period. Shelved indicates projects whose development has been halted in the absence of a definitive cancellation.

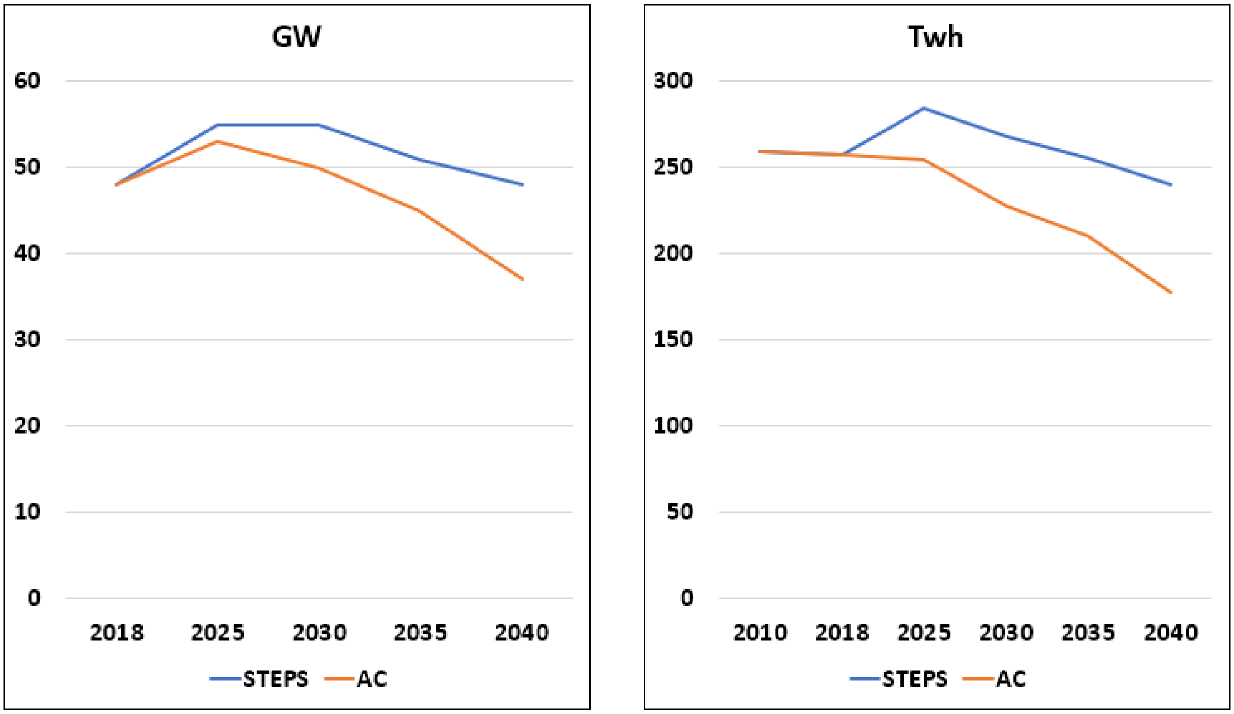
Source: Sub-Saharan Market Outlook 2020, BloombergNEF, 2020

To monitor future CO_2 emissions growth from the African electricity sector, it will be important to see if these trends towards closure/cancellation of coal-fired generation continue.

Since so much of the existing coal generation capacity and coal resource in Africa is based in RSA, it will be especially important to track activity there. As discussed further below, the national utility Eskom has recently run into severe financial stress – due in large part to cost overruns and poor performance of two large coal power plants in the past decade – which may lead to a major restructuring. In turn, Eskom's financial challenges may jeopardize plans for new coal capacity construction in RSA, while at the same time increasing the possibility that the retirement of the existing RSA coal fleet may be deferred.

Combining the effects of new construction and closure of existing plants, Figure 1-32 shows recent IEA projections for African coal-fired generation peaking sometime before 2030 and declining thereafter, reflecting some degree of completion of new projects gradually overtaken by retirements.

Figure 1-32: IEA Projections on African Coal-Fired Generating Capacity and Electricity Generation



Source: Africa Energy Outlook, IEA, 2019

Since the African electricity sector is currently capacity-short to a significant degree, it is questionable to assume – as the IEA has – that coal-fired capacity is retired and coal-fired generation will decline within the next few decades. Absent plans for a well-managed socially-just transition that replaces lost jobs and economic activity, significant forces at work will tend to keep existing coal power plants running.

In short, economic forces alone are unlikely to drive the retirement of existing coal power generation in Africa. If existing coal-fired capacity in Africa is to decline in the foreseeable future in order to drive CO_2 emissions downwards (notwithstanding the potentially negative effects on electricity supply availability), proactive environmental campaigns will likely be required.

One of the most important determinants of the rate of change in both renewable electricity and coal-fired electricity in Africa is the degree of expansion in natural gas fired generation across the continent.

Significant recent natural gas discoveries in SSA portend development and production of these resources for electricity generation (and other uses) across Africa. Discoveries in Mozambique, Tanzania, Senegal and Mauritania are estimated at 200 trillion cubic feet (tcf) that, when combined with Nigeria's proven gas reserves of 200 tcf, is thought to be sufficient to supply two-thirds of global gas demands for about 20 years.[xxviii]

However, increases in natural gas use in the African electricity sector will be limited if financing for natural gas pipeline construction is not viable, due to the risk factors discussed in further detail in section III. If meaningful expansion of pipelines does not occur, the only gas-fired generation possibilities for locations without nearby natural gas production will depend upon the development of liquified natural gas (LNG) infrastructure.

As of 2018, SSA countries have the capacity to produce and ship 34 million tonnes per annum (mtpa) of LNG – most of which is located in Nigeria. By 2025, this figure is expected to more than double, mostly due to a planned $50 billion investment to create a new 30 mtpa export facility in Mozambique. On the demand side, Ghana is installing 1.7 mtpa of LNG import capability in 2020 to supply 25% of the nation's electric power capacity (in lieu of oil), and Cote d'Ivoire, Morocco and RSA are also evaluating potential LNG import investments.[xxix]

While the economics of LNG importation have been improving everywhere in the world – especially in smaller-scale increments – financing of LNG export or import projects in African nations will, as is the case with all other kinds of energy infrastructure, often be challenging.

$1 Trillion in Capital Investment Requirements

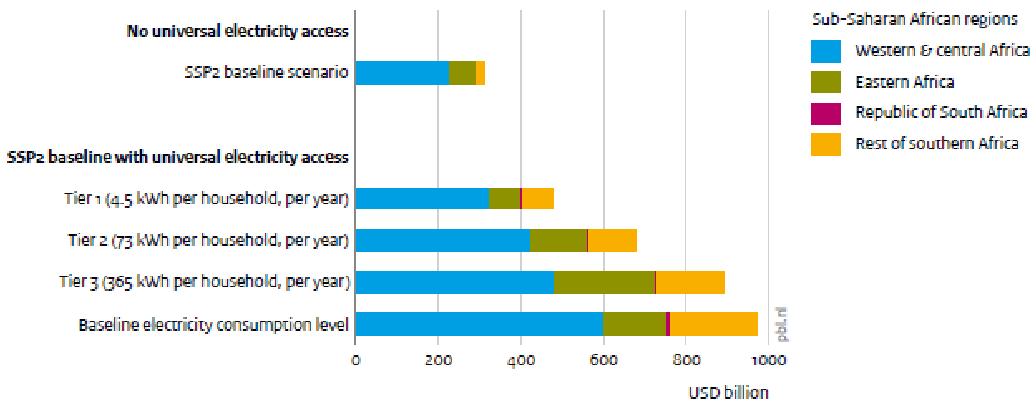
Translating the African electricity infrastructure expansion need into financial terms, BloombergNEF estimates about $245 billion in electrification investment across SSA to occur between 2018 and 2030 (i.e., about $20 billion per year) if universal energy access is earnestly pursued. However, this estimate appears to be predicated on very minimal levels of energy access, assuming 300 kWh consumption per year per household. As a result, the recent Bloomberg estimate of future investment requirements for African electricity system expansion falls on the low side of the spectrum.[xxx]

In contrast, McKinsey has estimated that $835 billion of capital investment – over $40 billion per year for the next two decades – would be required to satisfy projected 2040 electricity demand levels in SSA electricity. Of this amount, $490 billion (59%) is attributable to generation expansion.[xxxi]

Moreover, McKinsey's estimate of overall capital requirements to expand the African electricity infrastructure is generally corroborated by research from:

- The World Bank, which states that "estimates of annual investments required for the power sector between 2015 and 2040 range from $33.4 billion to $63.0 billion."[xxxii]
- AfDB's Programme for Infrastructure Development in Africa (PIDA), which states that an annual investment of US$ 42 billion (of which $33 billion for new generation additions) is needed through 2040 to meet forecasted electricity demand growth across Africa.[xxxiii]
- PBL, which (as shown in Figure 1-33) estimates nearly $1 trillion dollars of electricity investment (almost $50 billion a year) between 2010-2030 to achieve universal Tier 3+ energy access.

Figure 1-33: Total Investment in Sub-Saharan Africa Electricity Infrastructure, 2010-2030



Source: Towards Universal Electricity Access in Sub-Saharan Africa, PBL Netherlands Environmental Agency, 2017

Meanwhile, Figure 1-34 shows the IEA's more recent and comprehensive analysis indicating that the investment requirement in electricity infrastructure to achieve full (or near-full) energy access across SSA could be on the order of $100 billion per year.

Figure 1-34: Average Annual Power Sector Investments in Sub-Saharan Africa Between 2019 and 2040, Billions of 2018 US Dollars

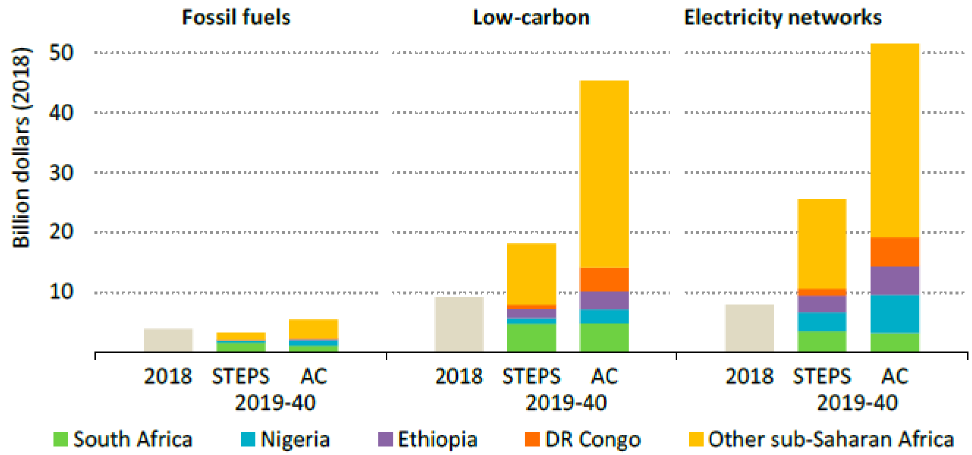
	Stated Policies Scenario			Africa Case		
	On-grid	Mini-grid and stand-alone	Total	On-grid	Mini-grid and stand-alone	Total
Total power plants	19.3	1.7	21.0	34.1	16.8	50.8
Coal	2.0	0.0	2.0	1.7	0.0	1.7
Natural gas	1.3	0.0	1.3	2.9	0.0	2.9
Oil	0.0	0.1	0.2	0.4	0.5	0.8
Hydro	4.4	0.0	4.4	7.7	0.0	7.7
Solar PV, wind, other low-carbon	11.6	1.6	13.2	21.4	16.3	37.7
T&D	25.3	0.2	25.5	49.0	2.5	51.5
Total	44.6	1.9	46.5	83.1	19.3	102.3

Note: T&D = transmission and distribution; Other low-carbon = bioenergy, nuclear and other renewables.

Source: Africa Energy Outlook, IEA, 2019

In either of the two IEA scenarios, Figure 1-35 shows that most of the investment requirement would flow to renewables and grid infrastructure, while investments in new capacity additions based on fossil fuels (almost exclusively associated with centralized plants) remain approximately at current levels.

Figure 1-35: Annual Average Power Sector Investment in Sub-Saharan Africa Through 2040



The investment gap is particularly large for renewables and electricity networks in both outlooks, and needs to accommodate more capital for natural gas in the Africa Case

Notes: STEPS = Stated Policies Scenario; AC = Africa Case. Low-carbon generation includes renewables and nuclear (nuclear only projected in South Africa).

Source: Africa Energy Outlook, IEA, 2019

Figure 1-36 provides a table summarizing these estimates, which suggests that minimally $20 billion per year – more likely $30-50 billion per year and potentially greater than $100 billion per year – is required to expand electricity infrastructure in Africa (mainly in SSA) to significantly improve energy access and availability.

Figure 1-36: Estimates of Capital Investment Requirements for African Electricity Expansion

Source	Annual Investment	Time Period	Geographic Breadth
BloombergNEF	$20 billion/year	2018-2030	SSA only
McKinsey	$33 billion/year	2015-2040	SSA only
World Bank	$33-60 billion/year	2015-2040	Africa
AfDB PIDA	$42 billion/year	Through 2040	Africa
PBL	$23-49 billion/year	2010-2030	SSA only
IEA	$46-102 billion/year	2019-2040	SSA only

Minimally $20 billion/year
More likely $30-50 billion/year
Plausibly $100 billion/year

Source: ISE original

Recent investment levels in the African electricity sector appear to be on the low end of this spectrum, which in turn may be well above longer-term historical averages.

As Figure 1-35 indicates, about $20 billion was invested in SSA on electricity infrastructure: $4 billion for fossil generation, $9 billion for renewable generation and $7 billion for transmission and distribution (T&D) networks.

However, even this degree of investment may be atypically high: elsewhere, the World Bank estimates that $29.8 billion was invested in electricity generation in assets in Africa between 1990 and 2013.[xxxiv] Since generation typically represents around half of the asset base of a comprehensive electricity system, this World Bank estimate implies that about $60 billion in total electricity infrastructure investment in Africa during this period, which equates to less than $3 billion per year over a prolonged span of time.

Recall further that the estimates presented in Figure 1-36 of capital requirements for African electricity infrastructure expansion are based on providing customers newly connected to the grid only relatively low degrees of energy access. If per capita electricity consumption in African nations is to be elevated towards developed-world levels, a far greater amount of investment would be required to commensurately expand electricity infrastructure.

Therefore, over the course of the next two to three decades, the aggregate capital requirement for expanding African electricity infrastructure is easily on the order of $1 trillion.

It is important that such large magnitudes of capital be deployed wisely in pursuing an appropriate set of infrastructure development opportunities – both to most efficiently bring power and progress to African people, and to do so in an environmentally-sound manner.

Because the installed African generation mix is so heavily dominated by fossil fuels, if the current electricity infrastructure is merely expanded from its current state with the generation mix held constant, CO_2 emissions from the African electricity sector would multiply accordingly. Simply expanding the African electricity infrastructure with “more of the same” is inconsistent with the global imperative to rapidly reduce CO_2 emissions to mitigate the threats associated with climate change.

II: Alternatives for 21st Century African Electricity Sector Expansion

Development of the installed African electricity infrastructure has generally followed the pathway blazed nearly 100 years ago on other continents: the construction of high-voltage transmission lines extending out from urban areas to large power generation facilities located in the countryside, all built to provide shared universal electricity service via distribution monopolies (for most African nations, usually state-owned).

Alas, as shown in the previous section, these efforts have not created an electricity system that serves Africa well, in turn poorly positioning the continent for the future. Across most of SSA, energy access rates, electricity reliability levels and electricity consumption per capita are amongst the lowest in the world, providing a weak platform for economic growth and social advancement.

For climate reasons alone, building out a pan-African grid to close the energy access gap by following the 20th Century roadmap for electricity sector development – involving large centralized generation plants (typically fossil fuel based, augmented by large hydro) and long-distance transmission to distribution networks – would be damaging. It's also becoming increasingly doubtful that such a pathway would be least-cost.

Fortunately, there are two promising sets of options for electricity infrastructure expansion that until recently had not sufficiently advanced to be economically viable in most circumstances:

- Centralized renewable energy sources (other than hydro and geothermal), notably solar and wind
- Distributed energy resources (DER)

These two set of options, blended in region- or country-specific optimal mixes, offer the promise for a development path for the African electricity sector that takes fuller advantage of 21st Century technologies and business models – producing zero (or near-zero) CO_2 emissions and more suitably configured for the spatial distribution of population and existing electricity infrastructure in Africa.

With technical improvements yielding significant cost reductions over the past few decades, these two approaches for electricity expansion are now often the most economic, and are usually more environmentally sustainable, than traditional electricity infrastructure choices. With appropriate consideration by government authorities, sector planners, and the financial community, Africa may be better able to capitalize on these two sets of options than other continents that have already committed to infrastructure based on 20th Century paradigms.

Each of these two emerging pathways for electricity sector expansion is discussed further below.

Centralized Renewable Energy

Electricity production based on renewable resources is not a new phenomenon. Hydroelectric and geothermal facilities have long been viewed by utilities and grid operators as just another power generation option, albeit with "fuels" that have zero marginal cost and – crucially, as the world aims to address climate change – do not produce any emissions. As such, attractive options for additional large-scale hydro and geothermal capacity in Africa are worthy of exploring to help address the continent's pressing needs for new zero-emission electricity supply.

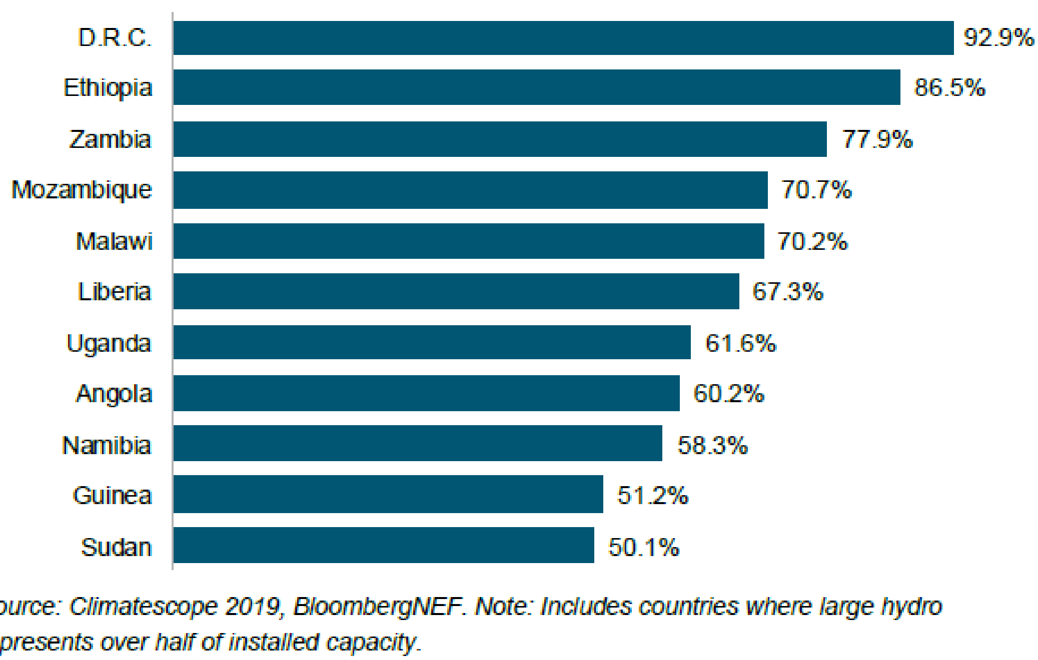
(Note: this paper has excluded consideration of biomass energy – another category of renewable resources – because they are extremely difficult to characterize in summarized form. In any event, since biomass electricity generation is generally not seen to be a major contributor – present or future – to Africa's electricity sector, this exclusion is not seen to be material to the findings of this paper.)

Traditional Renewables: Hydro and Geothermal

In many parts of the world, the first significant electricity generating facilities in many parts of the world were renewable: hydroelectric plants capturing the ability to use the flow of water in rivers as a reliable source of kinetic energy.

In Africa, 35 GW of hydro is already in the generation capacity mix, accounting for 16% of electricity production on the continent.[xxxv] In 11 African countries, as depicted in Figure 2-1, hydroelectric generation represents a majority of the capacity provided by the national power generation fleet.

Figure 2-1: Large Hydro As A Share of Total Installed Electric Generating Capacity, 2018



Source: Sub-Saharan Market Outlook 2020, BloombergNEF, 2020

Moreover, the installed hydro base represents only 11% of Africa's theoretical hydro potential, so hundreds of gigawatts of untapped hydro development opportunity remains across the continent. Reflecting this unrealized potential, 17 GW of additional hydro is now estimated to be under construction in Africa.[xxxvi]

The scale of hydro resource potential in Africa is so extraordinary that it is tempting to view hydro as an all-encompassing solution to most if not all of Africa's electricity needs. This temptation must be avoided: while development of additional large-scale hydro capacity in Africa can be worth pursuing, caution is warranted.

Without appropriate sensitivity to environmental concerns, massive new hydro development in Africa would significantly alter the ecology of many large areas of the continent, including the destruction of many important ecosystems that are critical contributors to carbon absorption. Altered ecologies trigger massive adaptation as life adjusts to impacts, in turn leading to altered microclimates which impact rainfall, temperature changes that alter water balances, and potentially incalculable impacts that can generate a protracted period of surprise outcomes with unknowable consequences.

Moreover, large hydroelectric projects often cause significant social dislocations, uprooting communities that are flooded for water collection above dams. It is for these reasons that the World Bank established its Inspection Panel in 1993 to serve as a forum for stakeholders to ensure that their local interests are appropriately considered during project development.[xxxvii]

Also, Africa is highly vulnerable to changing weather patterns due to climate change.[xxxviii] Because of this, Africa may be wise to avoid undue reliance on hydropower, given that historical rainfall patterns underlying hydroelectric resource projections are under threat if drought conditions worsen.

In addition, many of the best undeveloped hydro opportunities in Africa are at the gigawatt scale, requiring multiple billions of dollars to complete – especially when considering likely investments also needed to construct long-distance high-voltage transmission lines that carry large volumes of electricity to distant demand sites. As discussed in Section I, the African electricity transmission system and electricity demand levels are generally inadequate to support incremental projects of this scale.

Even where existing grid assets and customer demands could “fit” a project of this magnitude, it would be necessary to coordinate development activities across multiple countries, as the capital requirement would far exceed the financing capability of any one nation.

On top of this, many of these project opportunities are located where extreme country risk is likely to inhibit financing.

To illustrate this litany of challenges facing new large hydro projects, consider two examples:

- The Grand Inga Hydroelectric Project offers a theoretical capacity of 42 GW located in the Democratic Republic of the Congo (DRC). (Note that 42 GW is equivalent to nearly 20% of the currently installed base of electricity generation in all of Africa.) Rich in natural resources, the DRC is nevertheless one of the poorest countries in the world, with very low levels of energy access (<10%) and electricity consumption per capita, and virtually no electricity connections to other countries.[xxxix] Because of these factors, the only viable development plan for Grand Inga involved completion in phases. Accordingly, a nine-phase construction plan was developed, with the first phase (351 MW) completed in 1972 and the second phase (1,424 MW) completed in 1982.[xl] While the first phase of Grand Inga was always envisioned to supply the DRC’s capital city, Kinshasa, the second phase was intended to power mining activities farther east – but was completed five years before required transmission upgrades, and this delay caused the newly-constructed dam to deteriorate before it even became operational. Subsequent phases of Grand Inga have since been delayed, although some possibilities for resuming development were revived when RSA in 2011 signed an MOU to purchase 2,500 MW of the 4,300 MW planned third phase of Grand Inga.[xli] However, given the need for a several-thousand kilometer high-voltage transmission line to be built to connect Grand Inga to RSA, as well as the deteriorating economic condition of RSA and its national utility Eskom (discussed further below), any near-term commencement of further construction at Grand Inga is highly questionable.

- The Grand Ethiopian Renaissance Hydroelectric Project has a budget of $4 billion and a projected capacity of 6,450 MW.[xlii] Completion of this project alone would more than double Ethiopia's installed capacity of 4.2 GW.[xliii] Alas, international financiers have shied away from this project since its announcement in 2011 because the Blue Nile River, which the project would dam, supplies 90% of the downstream Nile River through Egypt, and Egypt claims hegemonic control over the water resources of the Nile, along which 95% of Egyptians live.[xliv] Due to the political tensions that this project could potentially cause between Ethiopia and Egypt, foreign investors have deemed project risks to be too high to provide financing.

These two examples illustrate some of the issues that arise wherever new large-scale projects – hydro or otherwise – are proposed. While the barriers to deployment are distinctive for each project, there are common underlying factors. Because large-scale hydro facilities can disrupt local and regional ecosystems and change the political dynamics between countries, national level policies regarding conventional hydro development merit updating. To the extent that new large hydro projects are pursued in Africa, cross-border coordination including joint planning and implementation should be a priority.

As a result, while certainly some amount of new hydro development is likely to occur – and should occur – in Africa, it is also the case that most of the massive hydro potential available on the continent will not – and likely should not – be developed.

Like hydro, geothermal energy is a well-proven renewable energy source for electricity generation. With substantial operational experience around the world since the 1970's, geothermal power stations exploit subterranean heat sources to generate steam for electricity production.

The primary challenge facing those that would seek to pursue new geothermal project development opportunities is that there simply aren't many places in Africa, as elsewhere on the planet, with geologic conditions that are conducive to economically viable deployment.

The East Africa Rift System (EARS) is one such location, transecting through Ethiopia, Kenya, Uganda, Rwanda, Burundi, Zambia, Tanzania, Malawi and Mozambique. Resulting from the rich geothermal resources of the EARS region, nearly 700 MW of geothermal power generation capacity has been developed in Kenya.[xlv] As additional transmission lines can be built, expansion of geothermal capacity can plausibly be developed in Kenya and neighboring countries in the EARS region. The Geothermal Energy Association estimates the theoretical geothermal potential of the EARS region at 15 GW.[xlvi] More realistically, future geothermal development opportunity in the EARS region is likely to be on the order of a few gigawatts at maximum, given that only 700 MW has been developed to date.

Thus, while selected opportunities may be very attractive and viable to pursue – and should be pursued where reasonably possible – neither geothermal nor hydroelectricity are likely to be major factors in closing the massive pan-African energy infrastructure gap.

New Renewables: Solar and Wind

Over the past thirty years, two renewable energy options have surged to the fore and are now receiving the most attention: solar energy and wind energy.

Until recently, these two technologies were widely considered impractical or inviable for large-scale electricity generation, but they have matured well: owing to significant technological advances, costs have fallen by orders of magnitude and conversion efficiencies have improved dramatically.

As a result of these cost improvements, both types of renewable energy can frequently deliver electricity at cost levels competitive to conventional fossil fuel-based production – at least in locations where the available solar or wind resource is sufficiently abundant.

Some of the advantages of solar and wind are the same as those offered by hydro and geothermal: no fuel costs, low operating costs, and zero carbon emissions.

Arguably as important, solar and wind energy projects offer an advantage that alternatives involving hydro nor geothermal – nor fossil fuel (nor nuclear) – usually find difficult to match: smaller minimum increments of economic addition.

This advantage is important because it enables both investors and consumers to avoid the financial swings that often occurred when large-scale generation plants were constructed.

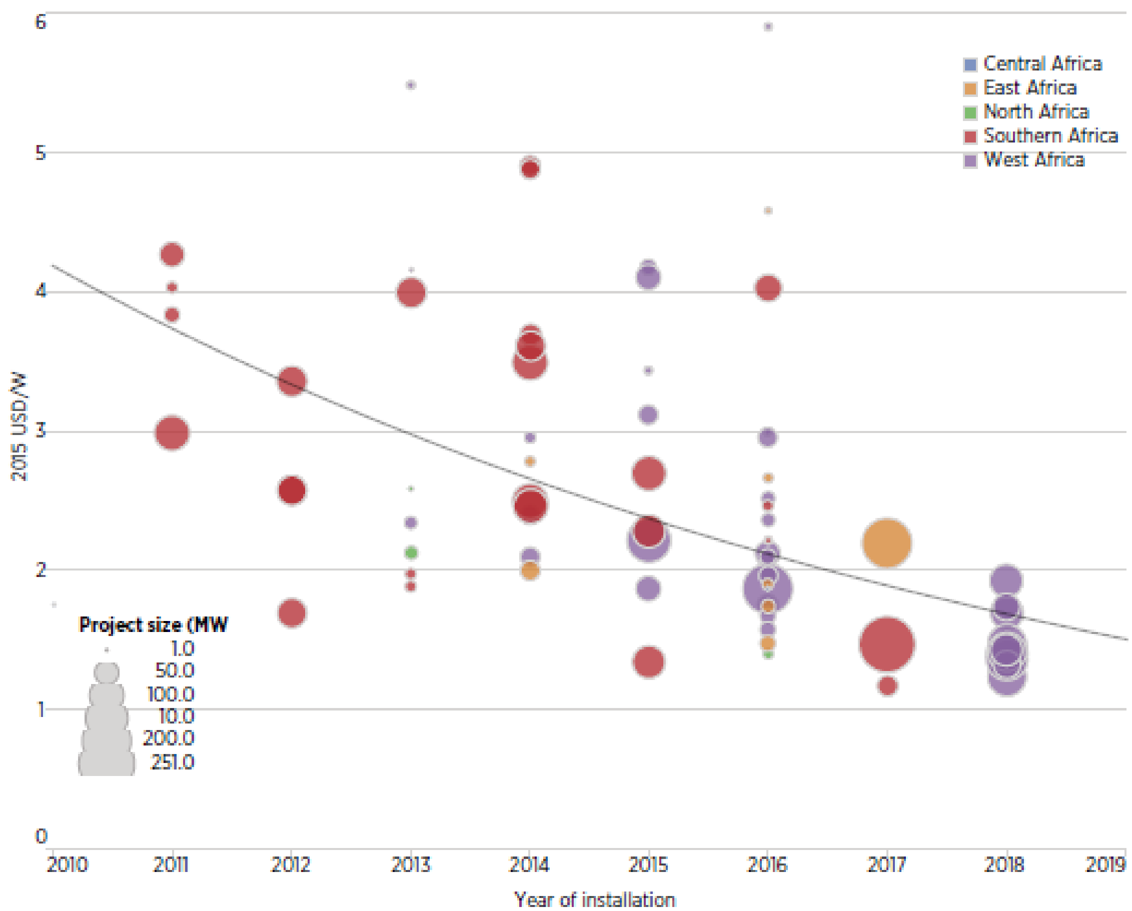
Historically, fossil and nuclear plants were subject to economies of scale, in which larger plants were cheaper to build – on a per-unit basis – than smaller plants. Accordingly, electricity systems were often expanded via capacity additions in larger increments than were truly needed at that moment, in the hope that expected future demand growth would soon materialize. In the meantime, substantial financial carrying costs on the surplus capacity were incurred until all of the capacity became "used and useful". Alas, if demand growth was slower than anticipated, the financial burdens of this arrangement could be quite significant.

Because they do not experience economies of scale, solar and wind energy are not subject to this risk. Rather than needing to overbuild and then wait for demand growth, solar or wind projects can be expanded incrementally as demand grows. Maintaining high utilization rates immediately upon project completion dramatically reduces financial risks and improves access to capital, by minimizing carrying costs.

Moreover, the flexible scalability of adding solar or wind capacity enables project developers to size the asset commensurate with local transmission capabilities. Put another way, even though per-unit costs may be somewhat higher, a small solar or wind development opportunity in Africa need not be economically impeded by the need to undertake a long (and expensive) transmission addition or upgrade.

Examining each of these two in turn, beginning with solar: Figure 2-1 shows the declining cost trajectory of utility-scale solar photovoltaics (PV) projects developed in Africa since 2010.

Figure 2-1: Declines in Installed Costs of Operating and Proposed PV Projects Recently Developed in Africa



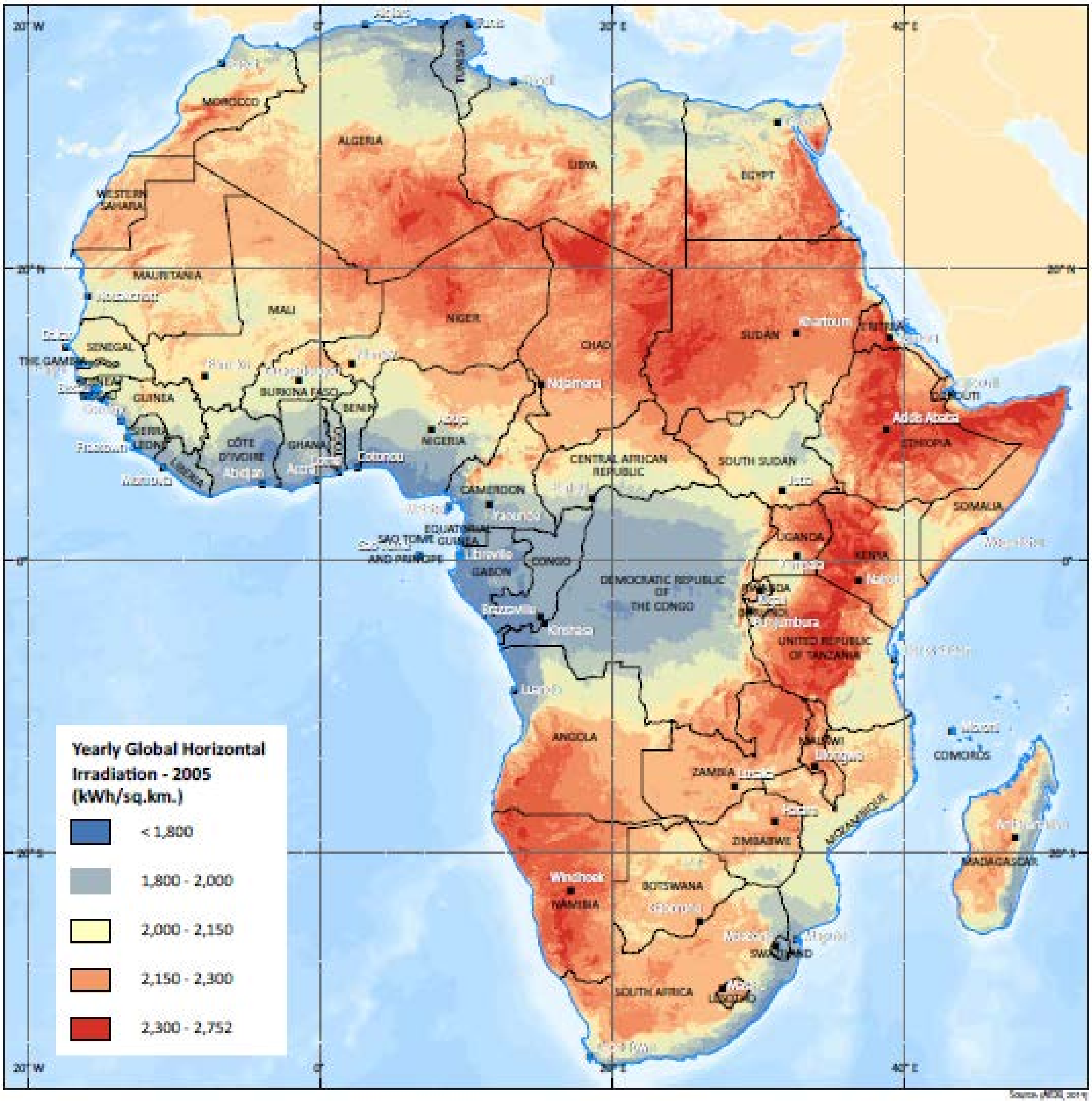
Note: Each circle represents an individual project. The centre of the cricle represents the value on the Y axis and the diameter of the cricle the size of the project.

Source: Solar PV in Africa: Costs and Markets, IRENA, 2016

Equally importantly to the improving economics of solar energy, Africa is fortunate to be blessed with significant solar energy resources. Most of the continent enjoys more than 300 days of bright sunlight and irradiance levels twice the average for Germany, where significant deployment of solar has occurred.[xlvii]

Figure 2-2 reveals a relatively uniform distribution of sunlight across Africa, with more than 80 per cent of Africa's landscape receiving high ambient insolation levels (> 2,000 kWh per square meter per year), thus implying economic suitability for PV across most of the continent.

Figure 2-2: Distribution of Solar Energy Potential in Africa



Source: Atlas of Africa Energy Resources, UNEP, 2017

It is only in recent years, since the costs of electricity based on photovoltaics (PV) technology have fallen sufficiently, that the promise of solar energy in Africa is starting to be realized more extensively. Starting from minimal levels a decade previously, installed PV capacity in Africa reached 4.5 GW in 2018.[xlviii]

The combination of improved economics and proven ability to adjust deployment scale to follow demand growth has made PV financing substantially more accessible in Africa, thereby reducing capital costs for developers. As a result, especially where it is sunny (as is widely the case in Africa), PV-based projects often can produce electricity at lower lifecycle costs than any other generation technology.

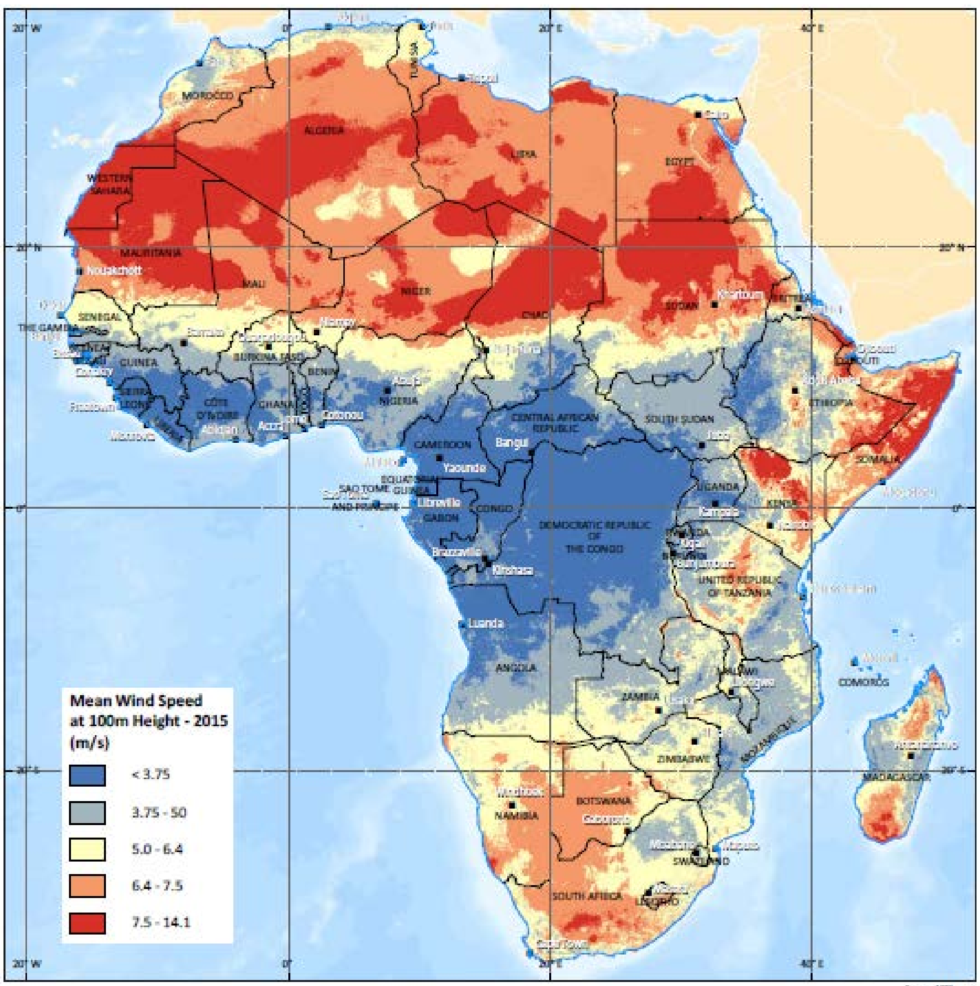
As a result, substantial long-term growth in envisioned for PV in Africa: by 2040, the IEA estimates 135-316 GW of PV capacity – nearly two orders of magnitude more than is installed today.[xlix]

Although this degree of market growth appears extreme, such expansion of African PV deployment nevertheless is feasible, as theoretical solar electricity generating potential in Africa has been estimated as high as 10 terawatts (TW).[l] At 10,000 gigawatts (GW), this is far more electric generating capacity than can be imagined for Africa's future needs for the forecastable future.

Therefore, the constraining factors for PV in Africa will not be availability of solar resources, but rather consumer electricity demand, ability to deliver electricity to users, and access to cost-effective capital.

Turning now to wind: the effective costs of wind energy are inherently lowest where wind speeds are consistently higher. As shown in Figure 2-4, the best wind resources are found in Northern Africa (especially across the Sahara Desert) and the Eastern Horn of Africa.

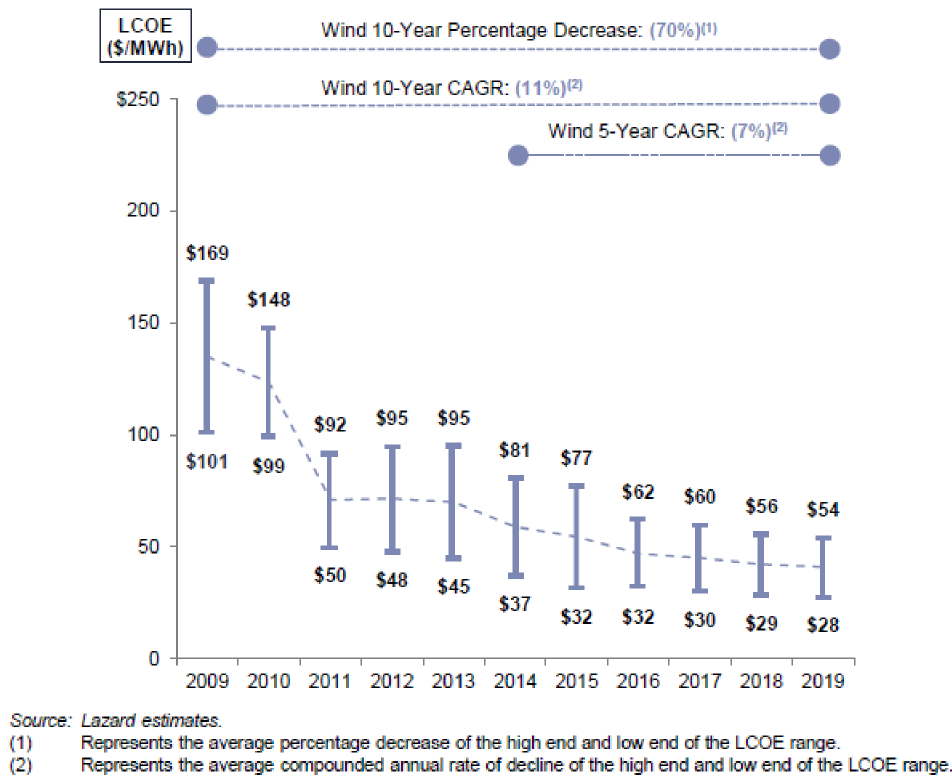
Figure 2-4: Distribution of Wind Energy Potential in Africa



Source: Atlas of Africa Energy Resources, UNEP, 2017

As with solar, wind energy deployment has advanced rapidly around the world because its costs have declined dramatically over the past few decades. Although Africa-specific data is not available, wind energy projects worldwide are experiencing a similar downward cost trajectory as solar energy, as illustrated in Figure 2-3.

Figure 2-3: Declining Levelized Cost of Energy for New Onshore Wind Energy Projects



Source: Levelized Cost of Energy Analysis v13.0, Lazard, 2019

Consequently, in windy locations, wind is now often economically competitive with fossil-based forms of electricity generation. While solar energy may often be cheaper than wind energy, wind energy is often a good complement to solar energy as it can provide generation at times (during the night, on cloudy days) when solar energy will otherwise be less available.

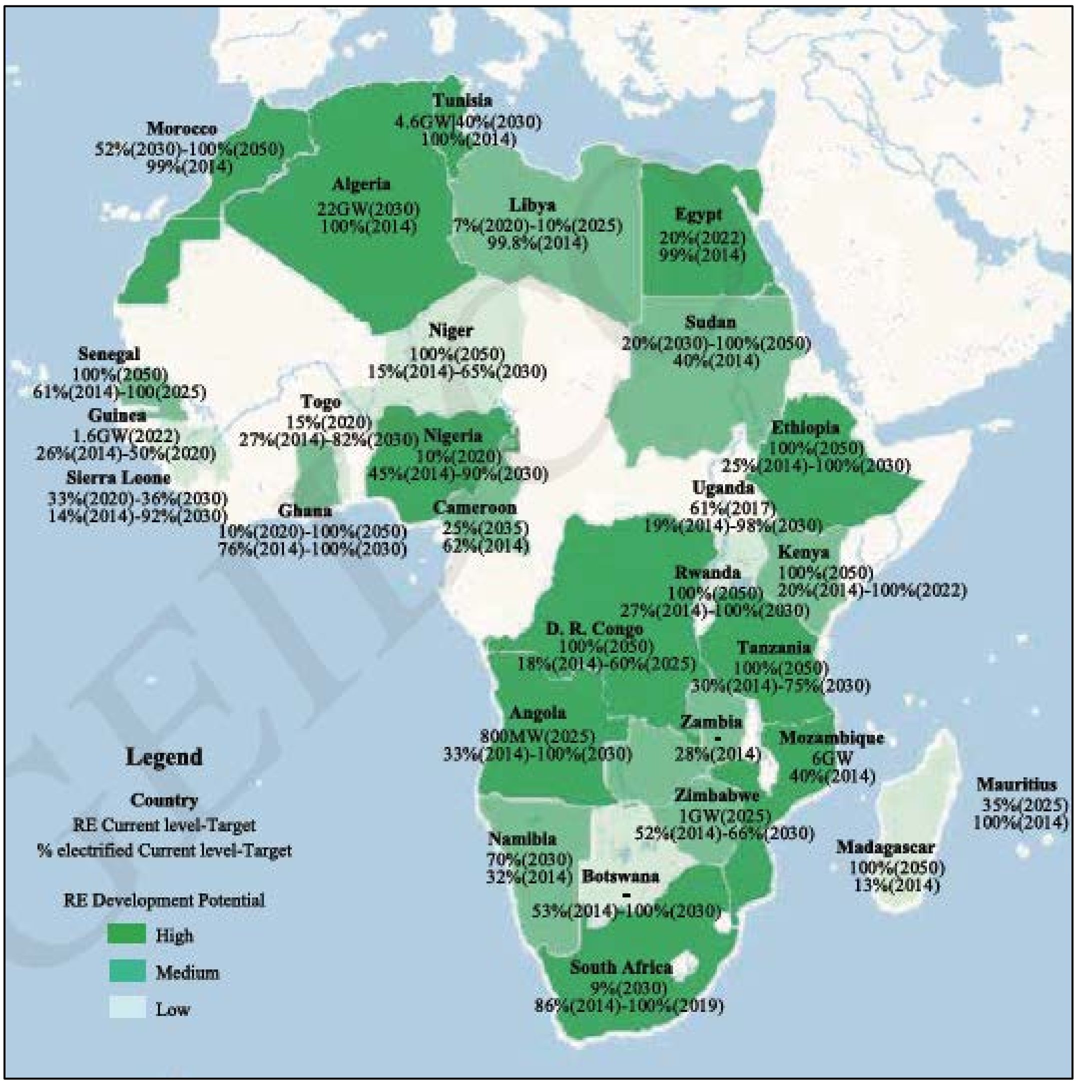
As of 2018, 5.5 GW of wind energy capacity had been installed across Africa, a five-fold increase from 1.0 GW in 2010. Going forward, the IEA estimates that wind energy deployment in Africa could grow by an order of magnitude, to 50-90 GW by 2040.[li] While this degree of growth is impressive, it nevertheless remains far below the theoretical maximum wind deployment of 1,300 GW across the continent.[lii]

Development of new centralized solar and wind projects will tend to utilize the business models and practices associated with development of traditional coal-fired or gas-fired power generation options that have been built in Africa in recent years. Depending upon the country's industry structure and regulatory regime, new centralized solar or wind projects will either be undertaken by a public-sector owned utility or by a privately-owned company, usually an independent power producer (IPP) under a power purchase agreement (PPA) signed with an electric utility or distribution company as counterparty.

Either way, the financial viability of a large-scale solar or wind project is fundamentally based on pricing levels for produced electricity and the creditworthiness of the power purchaser. As discussed below, these issues can often be obstacles in many African nations.

Another key "buy-side" variable affecting the pace of implementation of centralized renewables across Africa is how rigorously nations will enforce the renewable energy deployment targets that they have announced, as shown in Figure 2-5.

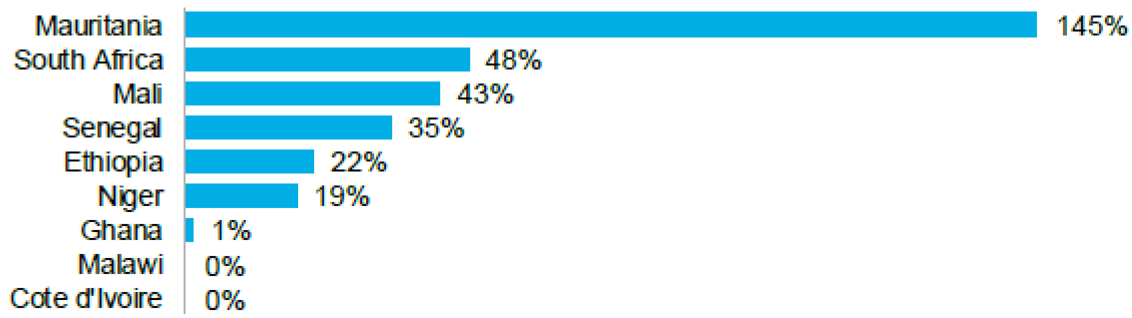
Figure 2-5: Renewable Energy Development Targets in Africa



Source: <u>Research on African Energy Interconnection</u>, GEIDCO, 2019

As Figure 2-6 indicates, progress towards achievement of national renewable energy targets in Africa has been uneven.

Figure 2-6: Progress Towards 2020 Renewable Energy Targets (as of 2018)



Source: Climatescope 2019, BloombergNEF. Note: Includes both renewables share and absolute capacity targets. Only 2020 targets set by 2015 included.

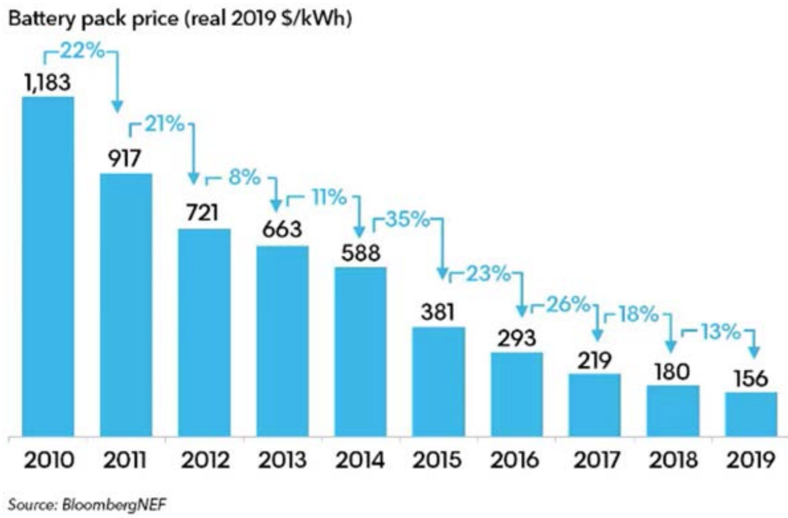
Source: Sub-Saharan Market Outlook 2020, BloombergNEF, 2020

Note that investors and lenders may drift away from engagement in financing renewable energy projects in countries whose governments do not follow through on their deployment policies and goals.

Although they do offer some clear economic advantages, it must be acknowledged that – unlike power generation options based on fossil fuels, hydro or nuclear – both wind and solar energy are intermittent forms of electricity supply that cannot produce their full rated output 100% of the time, simply because sometimes the sun doesn't shine and the wind doesn't blow.

Consequently, to maintain consistent operations on the grid, wind and solar energy generation capacity must be accompanied either by (1) other sources of dispatchable generation (such as hydro or fossil), or (2) energy storage. Fortunately, the costs of energy storage are falling, just as the costs of solar and wind energy have fallen in recent decades. Figure 2-7 shows the substantial decline in costs for lithium-ion batteries, the primary component of the primary energy storage system technology.

Figure 2-7: Declining Costs of Lithium-Ion Battery Packs in Energy Storage Systems



Source: "Low-Cost Batteries Are About to Transform Multiple Industries", Rob Day, Forbes*, Dec. 3, 2019*

As the costs of energy storage continue to decline, wind-storage and solar-storage hybrid deployments will become increasingly cost-effective, thus (1) reducing the need to pair fossil generation with wind and solar in order to maintain stable grid operations, and (2) making wind-storage and solar-storage economically attractive for new generation.

However, it should be noted that an increasing reliance by the African electricity sector on solar and wind, and utilization of energy storage to compensate for intermittency, is likely to require a significant upgrade grid operating and control systems. In developed economies around the world, enhancements in predictive analytics and control systems underway to accommodate growing utilization of renewable energy. Because the electricity sector in Africa generally lags global best practices, the required upgrades in Africa are likely to be even more significant.

Distributed Energy Resources

While centralized wind and solar are relatively new generation options to consider to augment the existing African electricity grids, a growing body of evidence points to a fundamentally different approach for electricity production and delivery as a superior pathway for closing electricity access gaps in many areas – especially in rural locations where the gaps are greatest and the costs of grid expansion are the highest.

As noted previously, the notion of isolated grids serving a very small geographic area is not new. Many mining sites in Africa are so far removed from the primary electricity grid serving urban areas that dedicated on-site power plants – mostly fueled by oil or petroleum products such as diesel – were constructed when the entire facility was built in order to serve the local industrial load.

What has changed in recent years is that improvements in materials and manufacturing technologies have enabled major cost reductions for so-called distributed energy resources (DER) better suited for non-industrial power supply needs. These include:

- Micro-hydro: small run-of-river devices, with an estimated 26 GW of theoretical development potential spread across the SSA[liii]
- PV: ranging from arrays of modules to supply a village to a few modules to supply a building to stand-alone devices (e.g., lamp, refrigerator) including embedded PV cells
- Energy storage: batteries (traditionally lead-acid, but now more commonly lithium-ion) to provide electricity when demand exceeds the ability of generation to meet supply

These DER technologies share several advantages:

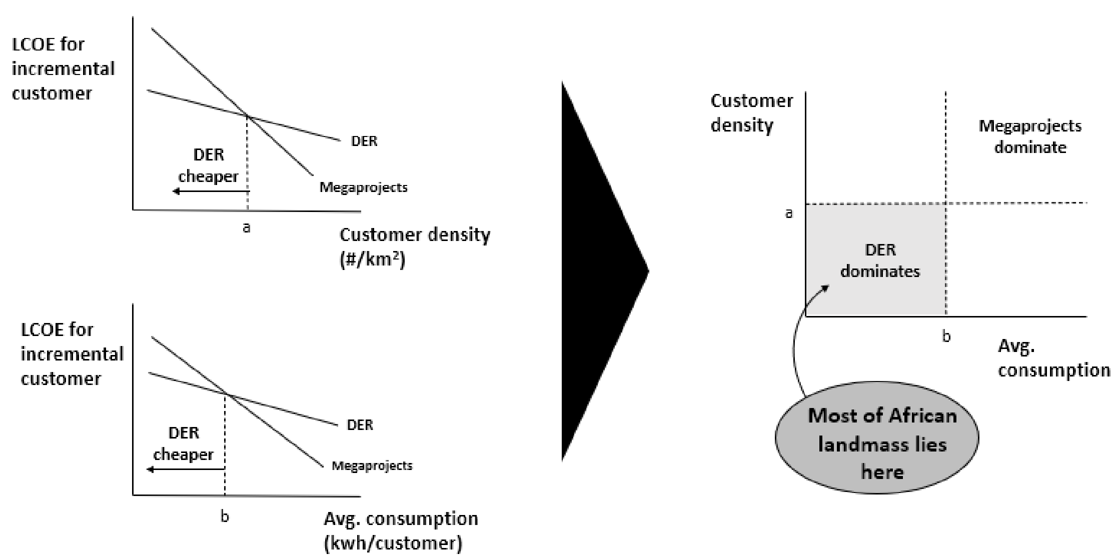
- The minimum economically viable size is very small (<1 MW)
- The minimum capital expenditure to initiate deployment is low
- The need for continuous provision of fossil fuels is eliminated
- The siting of projects usually presents much fewer challenges

As a result of these advantages, DER is transforming the basic economics of electricity delivery to rural low-density collections of electricity loads, such as the many unelectrified villages across Africa.

With ongoing cost declines, DER is increasingly becoming a viable option for adding electricity generation where the economics have never supported such investments.

Figure 2-8 provides a conceptual framework to illustrate the economic superiority of DER relative to "megaprojects" involving distantly sited generation (whether fossil or renewable) plus the addition of transmission and distribution to bring power to new customers not yet served by the grid.

Figure 2-8: Comparative Economics: DER vs. Megaprojects

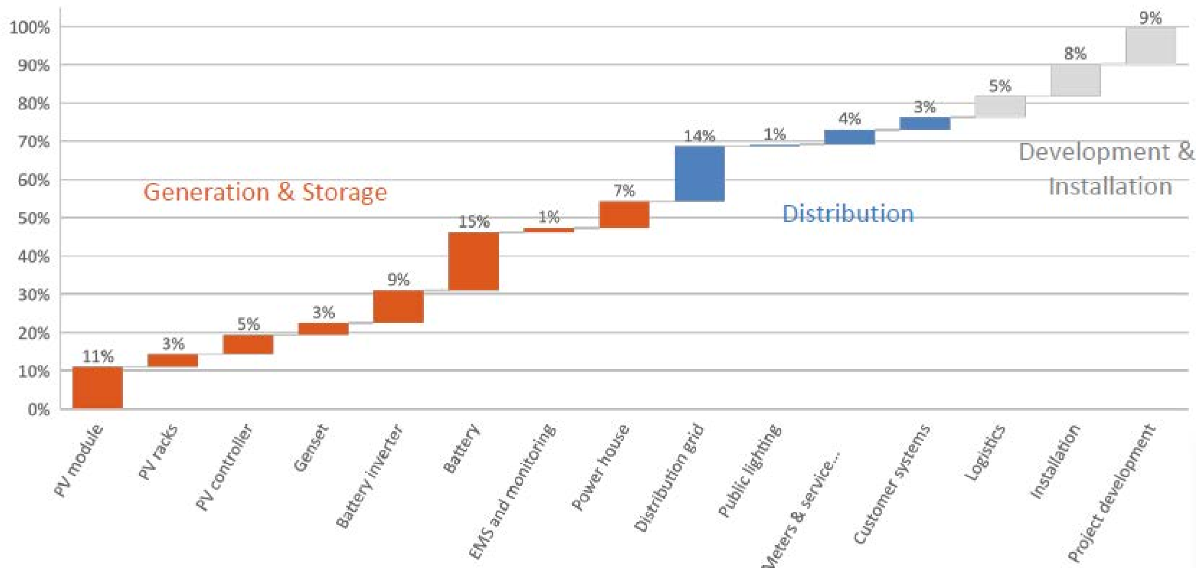


Source: ISE original

As can be seen, the economic advantage of DER stands out where customer density and average consumption is low – which is the case in much of Africa.

The implications of this trend towards DER for a continent with Africa's innate characteristics are potentially enormous. Rather than requiring wires to be strung across long unpopulated distances with virtually no economic activity along the way to help financially support the costs of the infrastructure expansion, DER-based systems can be located close to customer demands, thus reducing capital investment and ongoing expenditures on electricity delivery (both transmission and distribution). For a DER-based grid, at least half of the total cost structure is associated with small/modular generation (and energy storage) assets, as is reflected in Figure 2-9.

Figure 2-9: Decomposition of Typical Solar Mini-Grid Cost Structure



Source: Power for People, ESMAP

In most remote villages, where electricity consumption levels will usually be low (especially if starting from zero), electricity service is most economically be provided by a DER-based grid. The scale of a DER-based system serving a particular geographic area will inevitably be related to the number of households within the area and the degree of energy access and the corresponding amount of electricity consumption associated with the average household in the area.

With few exceptions, DER-based grids in Africa are or will be designed to operate autonomously, unconnected to the main electricity grid operated by the national utility.

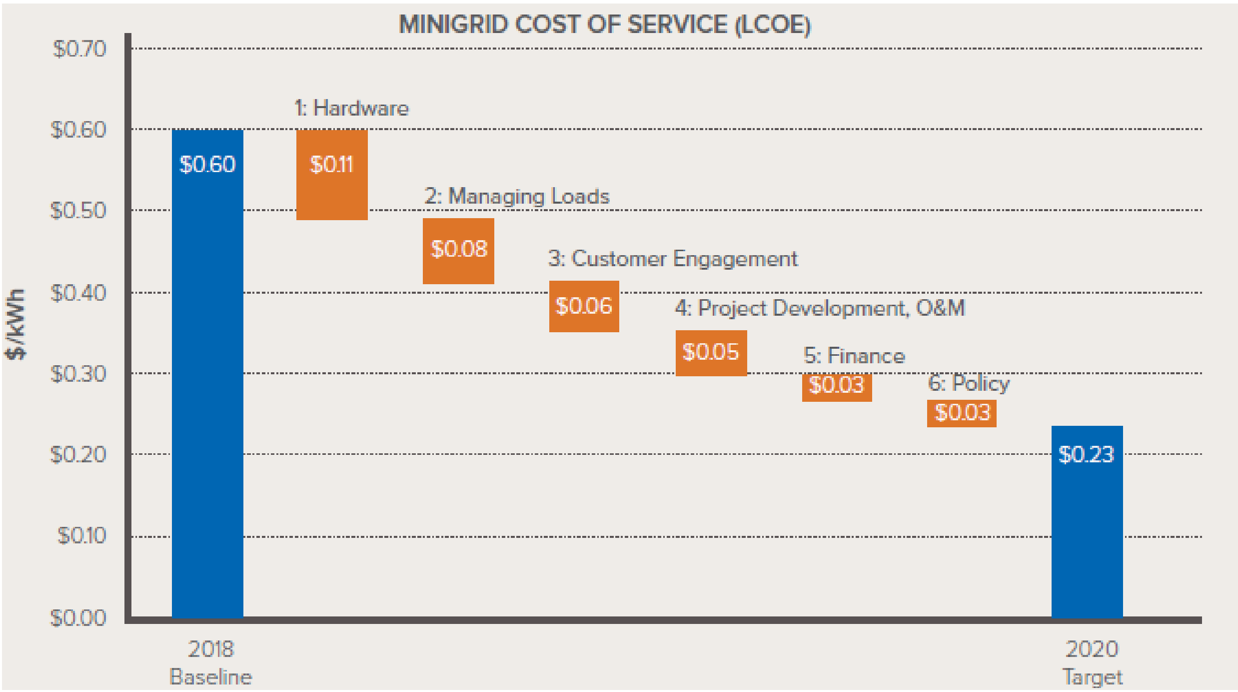
Note that a country's national grid is essentially a wide-area network, accommodating generation supplied from numerous power plants to supply multiple distribution circuits, each of which serves hundreds if not thousands of customers.

In contrast, DER-based grids are stand-alone systems, frequently called "off-grid systems", independent of the primary grid. They must have all the essential capabilities of the primary grid – electricity generation, balancing of generation with demand levels, delivery. As a result, DER-based systems are in most meaningful ways a very small electric utility.

However, because the load levels are smaller, the equipment for these DER-based systems does not need to be as heavy-duty as the equipment used on a nationwide grid serving gigawatts of electricity demand. Also, DER-based systems avoid all transmission equipment and eliminate many long-distance runs of distribution lines. Between these two factors, the capital costs of DER-based systems are far lower than the typical outlays associated with extending the primary electricity grid.

Except for the most remote locations, electricity service from DER-based systems is more expensive than from centralized grids. However, significant cost reduction potential has been identified in several aspects of DER-based grids, as depicted in Figure 2-10.

Figure 2-10: Cost Reduction Potential via Improvements in Mini-Grids



Source: Micrograds in the Money, Rocky Mountain Institute, 2018

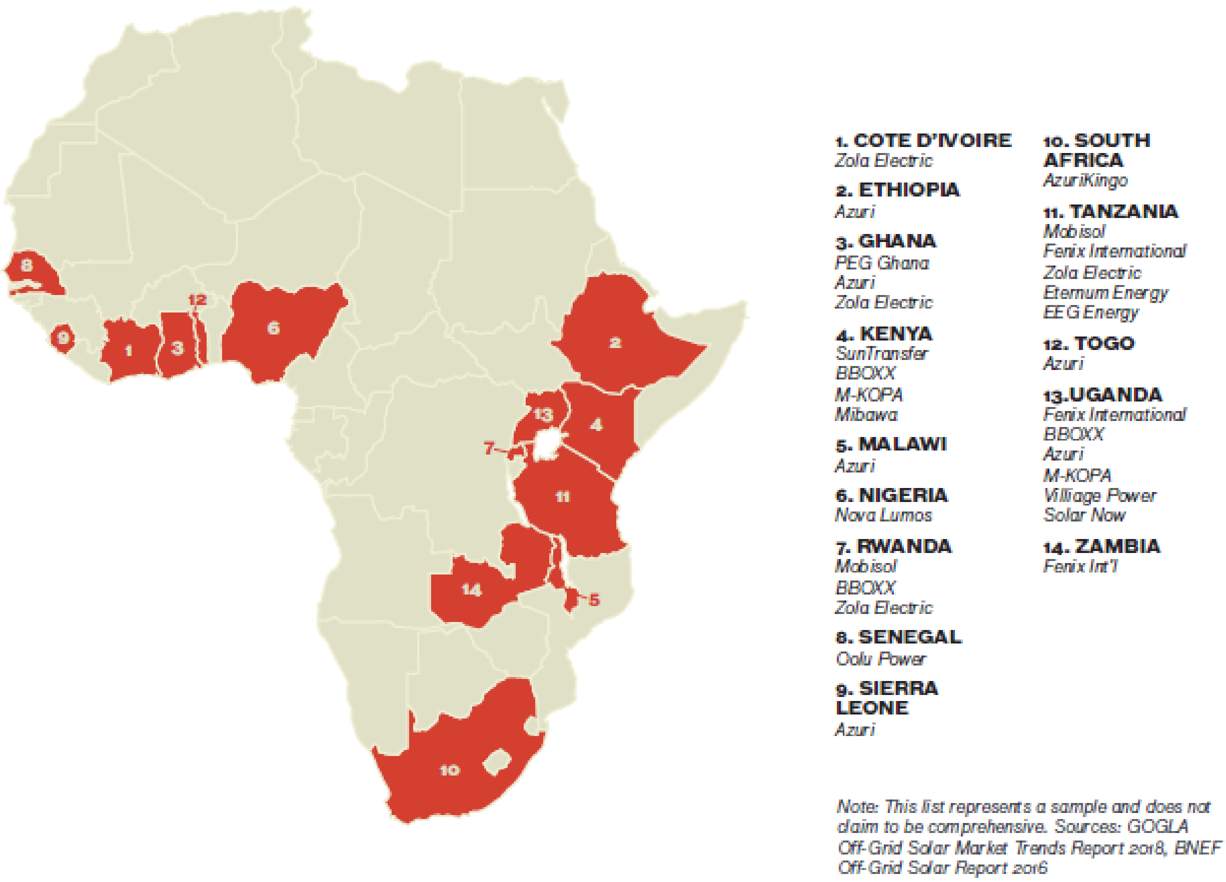
As the kinds of cost reductions presented in Figure 2-10 are realized, DER-based grids will become increasingly competitive in an ever-expanding set of circumstances and locations, with per kWh costs closer to conventional grid levels.[liv]

In most DER-based electricity delivery systems, service to customers is usually offered under a pay-as-you-go (PAYG) business model.

Under PAYG, rather than being billed after-the-fact for metered electricity consumption, the customer prepays the owner/operator of the DER-based local system for a given number of kilowatt-hours, the customer's meter is set by the owner/operator to enable the consumption of the purchased kilowatt-hours, and the customer then decides when and how much to use electricity until more electricity units are purchased.

As Figure 2-11 makes clear, the PAYG model has already gained notable traction across many rural parts of SSA.

Figure 2-11: Examples of PAYG Activity Across Africa



Source: Think Outside the Grid: Africa's Trillion Dollar Energy Opportunity, DBL Partners, 2018

Delivering electricity within a building, a village, or a few villages, DER-based systems of increasing scale can be classified into three respective categories:

- Mini-grids serving several villages that are relatively close together
- Microgrids serving one village consisting of dozens of buildings (i.e., customers)
- Nano-grids serving one building

(Note: this paper excludes a category of off-grid solutions smaller than a nano-grid called "solar home systems" (SHS), wherein an individual appliance such as a lantern or refrigerator includes an embedded PV power source. This is because most of these SHS products are designed to operate in a stand-alone manner, not to be part of any network. However, many electrification programs in SSA rely heavily on SHS for initial provision of energy access – even though it is very difficult to achieve anything beyond "Tier 1" access via SHS, and higher degrees of access will require a leap into at least a nano-grid.)

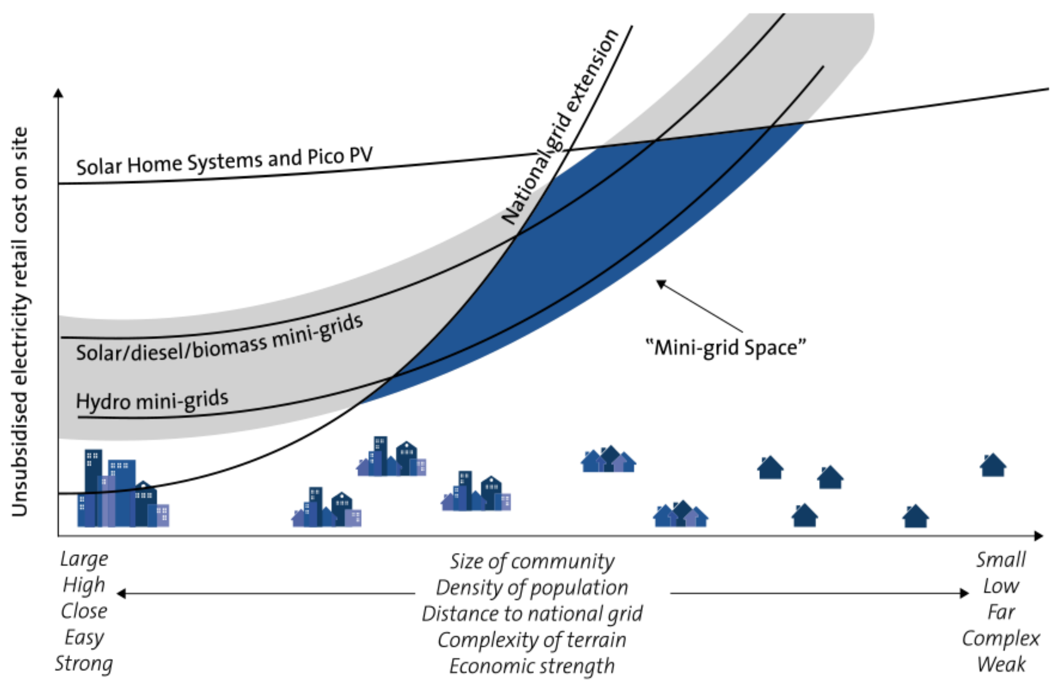
Each of these three categories of DER-enabled off-grid systems is discussed below.

Mini-grids

Mini-grids are localized electricity distribution networks that integrate on the order of 2-20 MW in total generation capacity. Mini-grids typically serve multiple communities that are close enough to each other (e.g., within perhaps 10 kilometers) to justify a common distribution network. A representative mini-grid in SSA would consist of a micro-hydro plant and some PV-based capacity (possibly backed up by a diesel generator) connected by a set of distribution lines to a handful of communities, including small commercial activity (e.g., shops), service businesses, light manufacturing, and households.

As shown in Figure 2-12, a mini-grid may be the least-cost solution for a regional cluster of moderate-scale communities that is otherwise remote from the national grid.

Figure 2-12: Economic Niche for DER-Based Off-Grid Solutions



Source: ISE original

As discussed below, a mini-grid can be the end-result of multiple micro-grids becoming integrated to exploit synergies. Accordingly, mini-grids and micro-grids share many operational and commercial characteristics.

Micro-grids

A micro-grid is technically defined to be a group of interconnected loads and distributed energy resources within clearly-defined electrical boundaries that acts as a single controllable entity.[lv] In practice, a micro-grid provides electricity from a set of generating resources – commonly on the scale of 0.5-5 MW – to a geographically proximate collection of buildings, such as a village. A micro-grid is usually stand-alone, although with growth may become interconnected with other nearby micro-grids to form a mini-grid, thereby enabling a more robust form of economic dispatch aimed at maximizing the utilization of shared generating assets and achieving more reliable electricity service.

Some African micro-grids were developed decades ago in areas unserved by the national utility, by early industrialists who installed diesel generators for electricity supply because the equipment could be manufactured at factories (mainly in Europe) and then shipped to Africa ready for deployment. While inexpensive to install and easy to repair/maintain, this decision committed these pioneering microgrid users to a constant need and expense for resupplying fuel – not always easy or cheap to recurrently deliver to remote locations in rural Africa.

Now, the declining cost of PV technology has made solar the favored generation supply option of present-day micro-grid development activity.

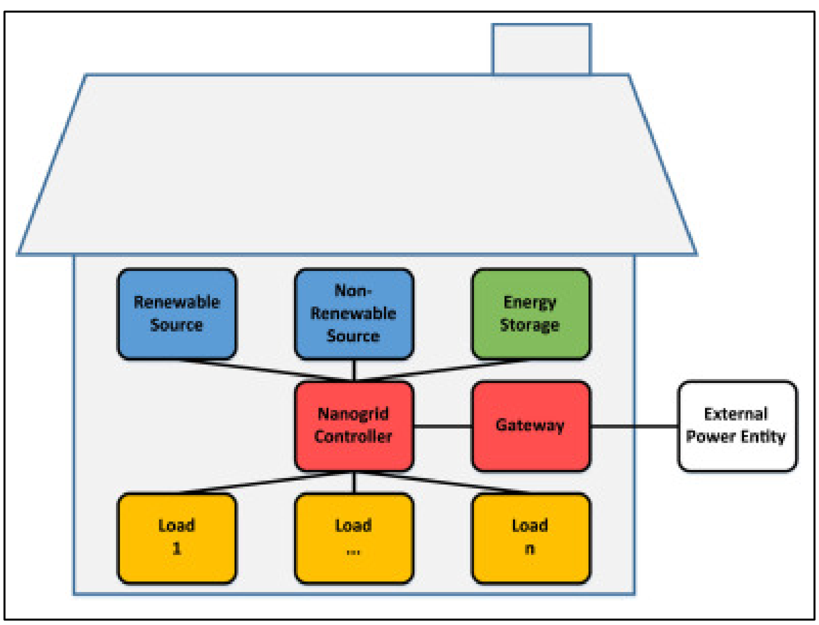
Nano-grids

A nano-grid comprises a single building power distribution system with a single domain for voltage, price, reliability, quality, and administration.[lvi] When multiple buildings equipped with nano-grids become connected, a micro-grid emerges.

The typical size for a nano-grid ranges from 1 - 1000 kW, with the lower end of the range reflecting a household and the higher end of the range representing a business customer. As with micro-grids, diesel generators have traditionally served as the main power source for many nano-grids, although this is transitioning to solar with the declining costs of PV.

A complete nano-grid includes the components shown in Figure 2-13: on-premises power sources, energy storage, a set of loads (served via circuits) associated with energy-consuming devices, a system controller, and (optionally) a gateway to enable interconnectivity.

Figure 2-13: Schematic of a Nano-Grid



Source: "A Review of Nanogrid Topologies and Technologies, Burmester et al, Renewable and Sustainable Energy Reviews, 2017

In general, there are two types of nano-grids: direct current (DC) and alternating current (AC). DC nano-grid systems are often preferred for low capacity appliances – such as lighting (usually highly efficient LED lighting), phone charging, and storage – due to lower costs, greater simplicity and fewer losses. Albeit at higher cost due to the additional need for an inverter, AC nano-grid systems are favored when supplying complex appliances with higher power requirements, including refrigeration and air conditioning.

Summarizing across the three DER-based grid systems considered herein: mini-grids, micro-grids and nano-grids all have the same fundamental characteristics. Each has a set of resources to generate electricity (increasingly augmented with storage resources) and a distribution network and control system to manage and deliver electricity to a set of devices that consume electricity. Each can operate autonomously, although they can also be structured to connect to the primary national grid also if desired. The only difference between mini-, micro- and nano-grids is scale: number of customers, magnitude of demand and generation, and geographic range.

"Grid of Grids": Mix of Centralized and Distributed Renewables

The preferred sector development strategy for an area with low electricity access – including most countries in Africa, especially in SSA – is likely to involve an optimized mix of two archetypes:

1. Expansion of generation capacity, improvements in generation and grid operational reliability, and selective strengthening and expansion of the T&D network and generating capacity in (and adjacent to) locations where the primary grid already exists and is salvageable
2. Deployment of DER-based grid systems elsewhere, and discarding pre-existing plans for adding new generating capacity and bringing the distribution grid to populations in vast sparsely populated regions

Although Africa already exhibits a combination of all organizational forms of grid infrastructure, from regional power pools spanning multiple countries to small nano- and micro-grids in localized villages, most of the historical focus on electricity sector advancement has been along the first dimension involving large-scale generation and transmission. In the future, DER-based grids will likely gain an increasing share of activity.

Over time, with the spreading deployment of small-scale grids, a hybrid state comprised of both larger grids and smaller grids will characterize a growing portion of the African landmass. This hybrid state will likely be constantly evolving, with grids attaching to each other in a quilt-like fashion, growing organically into a "grid-of-grids" covering much of Africa – assimilating existing grids and their associated generation assets.

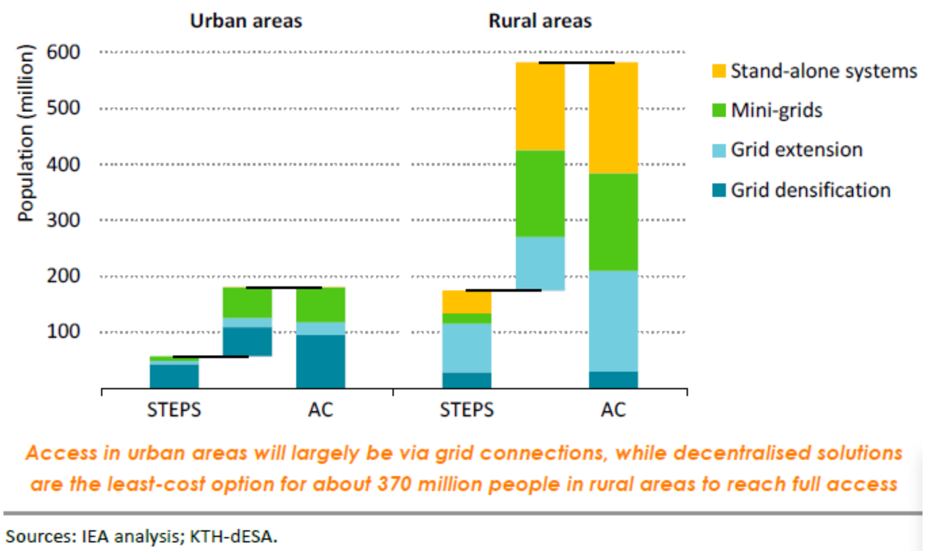
As this occurs, admittedly taking decades, a more meaningful degree of electrification can occur in Africa with maximum capital efficiency and minimum environmental consequences.

In this "grid-of-grids", different types of grids will emerge for different locations across Africa. According to the AREI, 68% of Africans projected to obtain energy access between now and 2030 will do so because of investments in centralized grid infrastructure, with the remaining 32% gaining access from DER-based grids.[lvii]

Meanwhile, BloombergNEF projects that roughly half of the electrification expansion investments in SSA through 2030 will be allocated to DER-based grids. Assuming African nations seriously aim for universal energy access, BloombergNEF anticipates that more Africans would obtain electricity via DER-based solutions (137 million) than via conventional grid expansion (92 million).[lviii]

This is consistent with IEA's analysis, shown in Figure 2-14, wherein a greater share of rural African population is projected to gain access to electricity via DER-based grids as/if a more ambitious electricity infrastructure expansion ambitions are pursued.

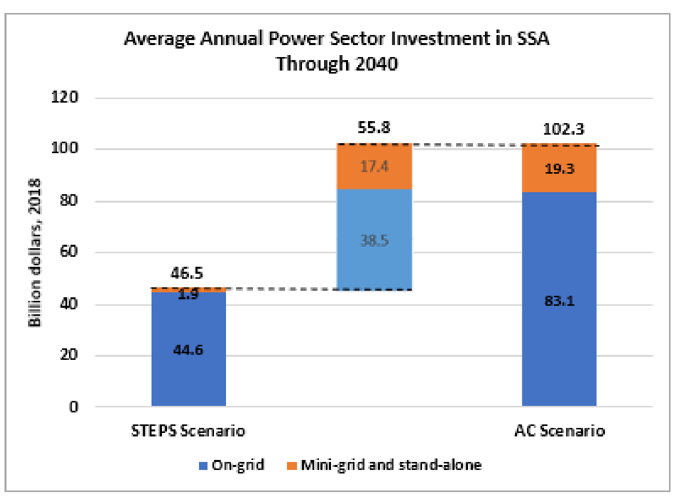
Figure 2-14: Incremental African Population Served By Alternative Electricity Expansion Modes



Source: Africa Energy Outlook, IEA, 2019

Elaborating, it is revealing to compare the share of aggregate capital deployed for centralized (on-grid) vs. distributed (mini-grid/stand-alone) assets in SSA under each of the two IEA scenarios.

Figure 2-15: Increasing Share of Investments in Off-Grid Electricity



Source: Africa Energy Outlook, IEA, 2019

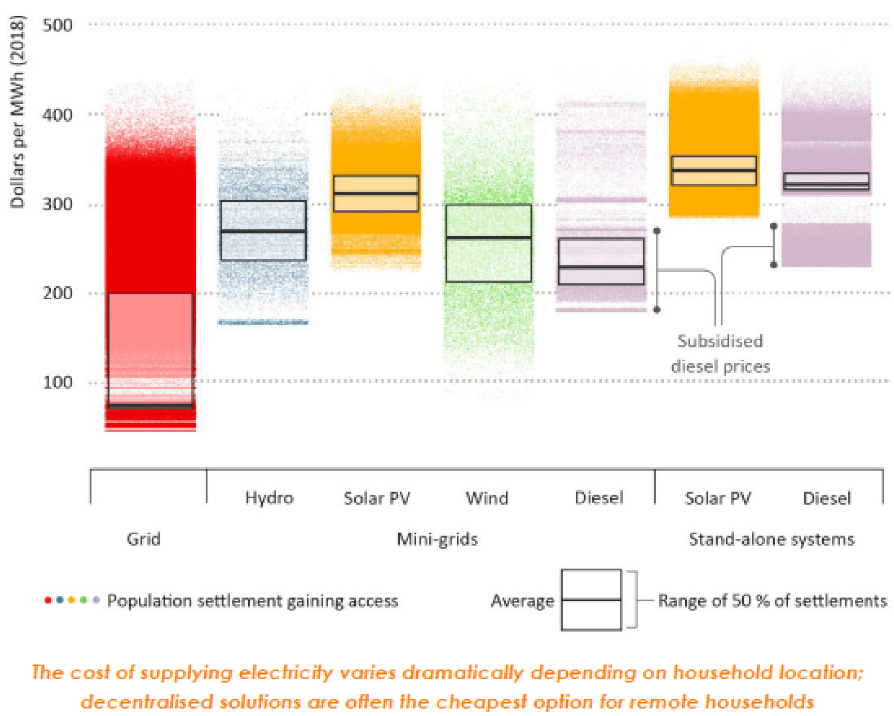
Figure 2-15 shows that virtually all investment in IEA's more conservative STEPS scenario is attributable to centralized infrastructure, whereas the share of capital going towards distributed grid assets increases significantly (to nearly 20%) in the more ambitious AC scenario.

The finding illuminated in Figure 2-15 implies that, as expansion of the African electricity sector transitions beyond the "lowest hanging fruit" – which almost wholly involves centralized grid assets – an increasing fraction of activity may turn to distributed assets: beyond the initial $46.5 billion of annual investments identified in IEA's STEPS scenario, over 30% of the incremental $55.8 billion (up to $102.3 billion) is attributable to distributed grid assets.[lix]

It would be interesting to determine if the "initial" reliance upon investments in centralized assets (as suggested by IEA's STEPS scenario) remains the case when the current economics of alternative energy technologies and approaches are considered, or is mainly an artifact of long-planned mega-projects that remain in the development queue (which may or may not be brought to fruition).

Which Africans obtain electricity via DER-based solutions (rather than conventional grid expansion) will be a function of both population density and distance away from the current grid, among other factors. As the IEA notes, while the least-cost electricity supply solution in Africa will often be the centralized grid, the cost of grid extension can be very high for the most remotely-located customers, making other DER-based options cheaper for those who are far away from the grid, as shown in Figure 2-16.

Figure 2-16: Levelized Cost of Electricity in 2030 for Alternative Approaches to Provide Energy Access in Sub-Saharan Africa



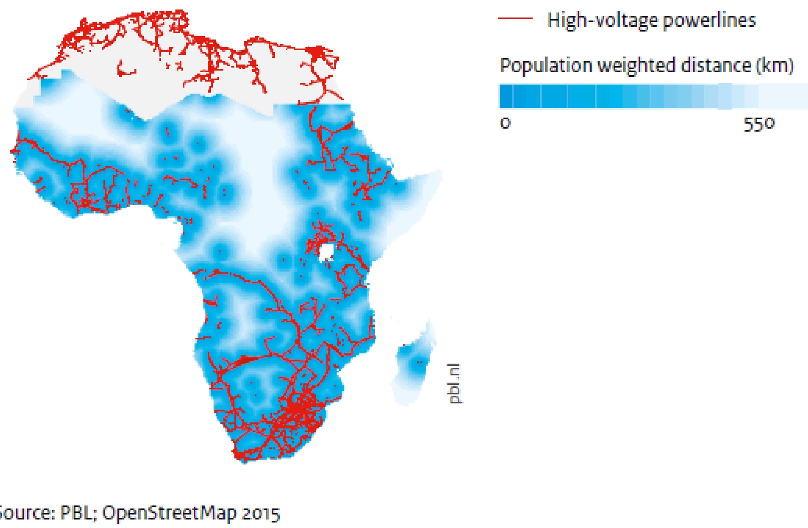
Notes: Each point represents an individual settlement in sub-Saharan Africa. It shows the LCOE of the least-cost solution determined for each settlement through our geospatial analysis (see Box 3.2).

Source: IEA analysis; KTH-dESA.

Source: Africa Energy Outlook, IEA, 2019

Note further in Figure 2-17 how geographic distance from the current grid varies dramatically across the African continent – and that many places are literally hundreds of kilometers from the grid.

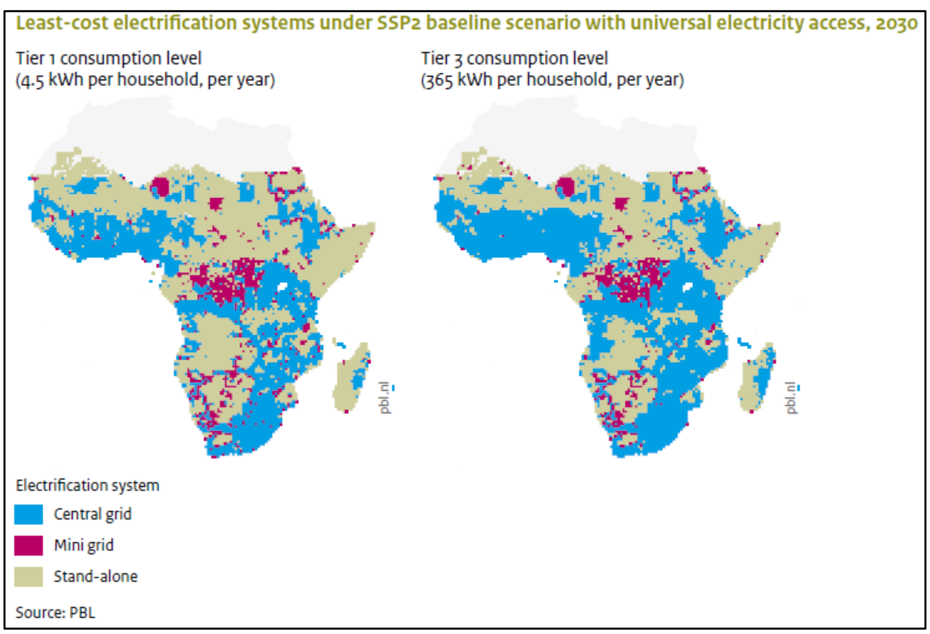
Figure 2-17: Distance from the Power Grid on the African Continent, 2010



Source: Towards Universal Electricity Access in Sub-Saharan Africa, PBL Netherlands Environmental Agency, 2017

Accordingly, many of the more remote areas of Africa will best gain energy access by DER-based mini-grid or so-called "stand-alone" (i.e., nano-grid or SHS) solutions, as exhibited in Figure 2-18.

Figure 2-18: Economically-Optimal Modes of Electrification Across Sub-Saharan Africa



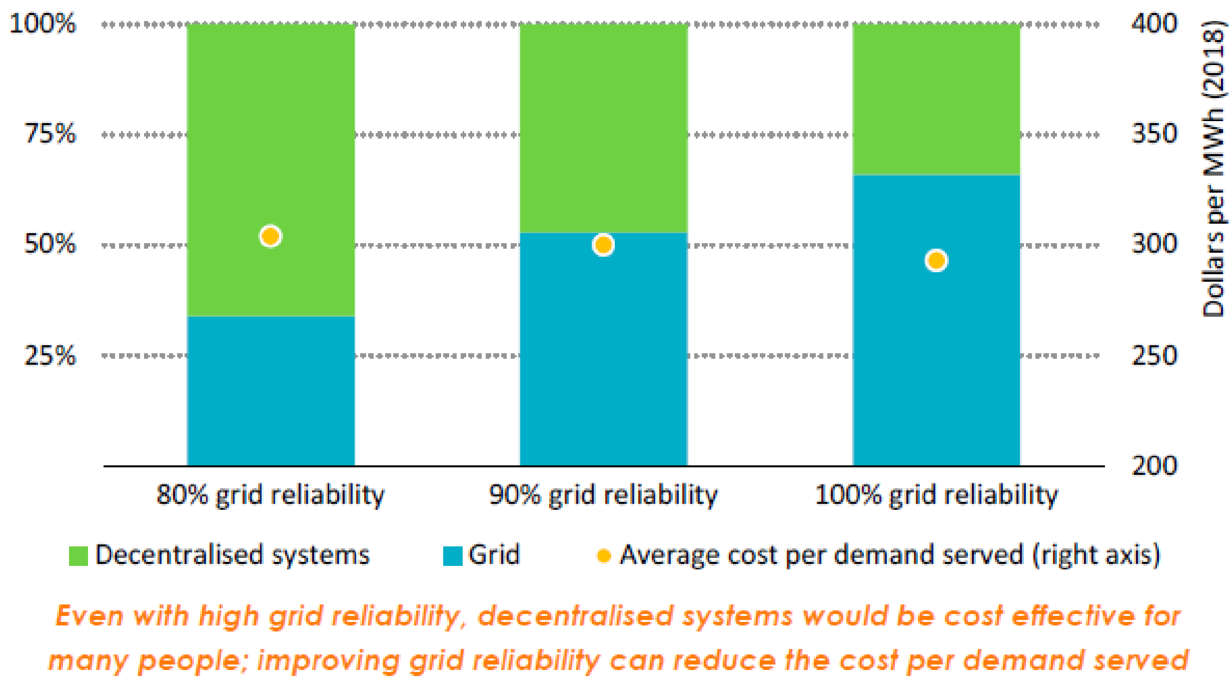
Source: Towards Universal Electricity Access in Sub-Saharan Africa, PBL Netherlands Environmental Agency, 2017

In any given location, the type of grid that should be employed and the associated infrastructure to be deployed will best match that area's particular characteristics:

- Locations with lower consumption density – typically villages, which tend to be poorer, and therefore costlier and riskier to serve – will tend to favor off-grid approaches involving less capital-intensive solutions, whereas
- Locations with lower risks and higher consumption density may justify the greater capital outlays associated with centralized generation expansion and associated transmission and distribution upgrades

Moreover, as can be seen in Figure 2-19 from an analysis conducted in Rwanda, locations that never had electricity before (and thus more tolerant of lower degrees of electricity availability) will be more well-suited for DER-based options that can introduce energy access in small and therefore more affordable increments.

Figure 2-19: Optimal Approach for Electrification in Rwanda Dependent Upon Desired Reliability Levels



Source: Africa Energy Outlook, IEA, 2019

The most significant initiatives in improving African energy access via DER-based approaches are concentrated in four countries: Kenya, Ethiopia, Tanzania and Nigeria.[lx] To illustrate:

- To achieve universal access by 2022, in addition to grid improvements, Kenya is planning 35,000 new connections through 121 new mini-grids, plus nearly 2 million deployments of standalone solar home systems.[lxi]
- In Ethiopia, universal access is expected to be achieved via 35% off-grid access and 65% on-grid access.[lxii]

Progress in these countries is enabled by well-defined rural electrification efforts and policies to facilitate third-parties to deliver off-grid solutions, leaving other players (including the government) to invest heavily in large electricity infrastructure projects – mainly hydroelectric and geothermal power generation – to improve availability of electricity supplies for customers in urban and semi-urban areas already connected to the grid.

As sustained economic growth is achieved, the various grids – both large centralized and numerous DER-based – can organically grow and begin to interconnect, thereby offering improved economies and resilience as the investments to make the connections can be afforded. Slowly but surely, Africa's utilization of local backup generation (especially diesel) to provide electricity during the continent's frequent and extended outages should decline as the lattice of grids interconnect and tighten.

Common everywhere will be an increasing reliance on renewable electricity generation, both centralized and distributed, because of continuing improvements in their economics. Solar will gain the biggest shares, but significant quantities of wind will be added as well – and both will be augmented with growing quantities of energy storage to mitigate the otherwise-intermittent nature of both wind and solar energy.

Although new centralized fossil generation opportunities will decline in appeal, it will be difficult to shut down existing fossil power plants – though efficiency and availability improvements can and should be gained where possible.

III. Impediments to Investing in African Electricity Infrastructure

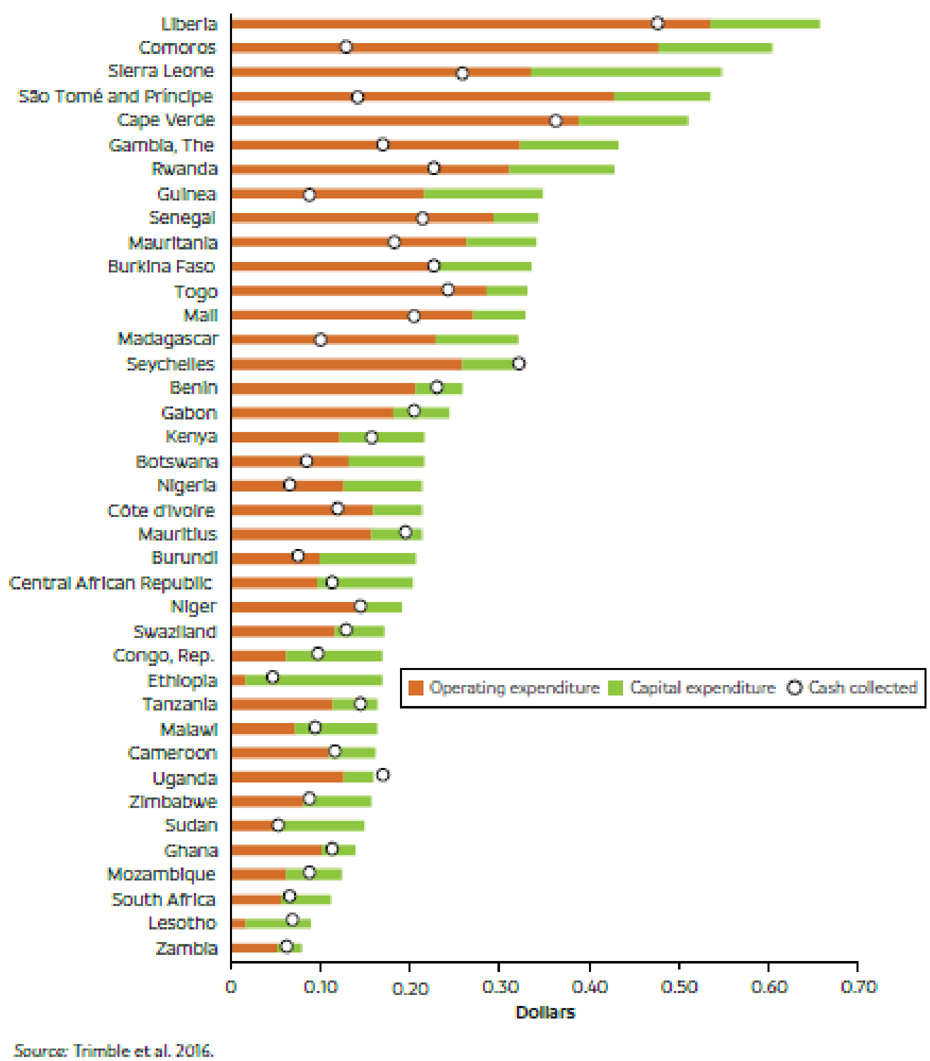
New approaches to electricity sector development, and to its financing, are necessary for Africa to promote economic growth and achieve its energy access ambitions – while also minimizing CO_2 emissions as the world combats climate change.

The capital that has been invested thus far in African electricity infrastructure has generally performed poorly not just in supplying electricity, but also in providing returns commensurate with risks absorbed.

Financial Insolvency of Most African Utilities

The World Bank recently studied the financial condition of the electricity sectors in 39 African countries, and discovered that most were financially insolvent.

Figure 3-1: Comparison of True Supply Costs and Cash Collected for Electricity in African Countries, in 2014 US $ per kWh



Source: Making Power Affordable for Africa and Viable for Its Utilities, World Bank, 2016

Summarized in Figure 3-1, the World Bank found in 2014 that electric utilities only in two countries – the Seychelles and Uganda – were fully recovering their operational and capital costs through revenues from customers, and that utilities were covering their operational costs in only 19 countries. Thus, in 18 countries (approximately half of nations investigated), the electricity sector was financially unsustainable: consuming cash from some external source of subsidization, and returning zero on capital investments.

A prominent example of this phenomenon is Eskom, the state-owned electric utility serving the RSA.

Until recently, Eskom and RSA were considered among the (if not the) best-in-class across the SSA for electricity sector development, and for economic development more generally. However, the situation at Eskom has deteriorated rapidly and dramatically, both financially and operationally. According to the introductory section of an October 2019 overview report of Eskom conducted by an independent reviewer:

> "While Eskom is a vertically integrated utility on paper, it has devolved into an operationally dysfunctional, financially insolvent, unreliable and corrupt entity…Eskom and South Africa are on life support, have no cash [and] no credit…Aggregate debt and liabilities are at least 2.3 times the total book assets of the company…There is no asset recovery available to the Company's public or private debt securities, project finance loans and other contractual obligations…The Company's cost of capital, interest maintenance and day-to-day operating cash flow gap have overtaken the commercial viability…The Company has no lenders of last resort given the disastrous state of affairs…The Company is fundamentally insolvent, permanently impaired, and will never be a true going concern enterprise under its current legal, operational and governance structure."[lxiii]

To better understand what went wrong at Eskom, the independent review continues:

> "Eskom is in serious trouble at the operational level, leaving aside the massive debt load, lack of governance and management, and systematic fraud. The company has deferred substantial maintenance liabilities on its entire fleet of generation, transmission and distribution assets, which is crippling the utility….Half of Eskom's generating capacity (excluding its two new stations Medupi and Kusile power plants) is either off-line, severely damaged, compromised, lacks spare parts, and won't be fully operational for another three (3) to five (5) years on a best case scenario…The utility is running its operating power plants at a loss and therefore has not accrued the necessary maintenance reserves required to operate and maintain the plants. The utility has for lack of better terms, run its aging coal fleet into the ground, causing the overall transmission and distribution grids to become more unstable and exponentially increasing the risk of complete system failure."[lxiv]

A major cause of many of these issues for Eskom seems to be the 2007 decision to build two new large coal-fired power plants, Medupi and Kusile, that have led to significant cost overruns and operational difficulties:

> "Construction at the new coal plants Medupi and Kusile has failed miserably, resulting in baseload plants constantly tripping off the Grid and have had non-stop design and operational/start-up problems…Eskom for no credible reason, decided to have these new

> multi-billion dollar coal plants custom designed, without going to a "Public Tender Process", and with no credible [EPC] contractor in charge. This has proven to be costly and devastating for the country of South Africa. The projects have been and are plagued by massive corruption, kickbacks and faulty construction."[lxv]

The report on Eskom provides much more detail in this same vein, vividly illustrating the potential downsides that can occur when financing African electricity infrastructure development.

Moreover, it should be noted that Eskom's cost overruns on major power projects are not unique within Africa. As McKinsey notes:

> "Power projects in Africa frequently overrun timelines and budgets; the larger and more complex the projects, the greater the overruns. Many international developers already include a premium or contingency of 20 to 30 percent for planning timelines (for example, productivity rates) and budgets on African projects compared with similar projects in a developed economy. But even those contingency amounts often fail to account for the total project expenses we see. Currently, a true 'African cost premium' would be about 60 percent, in our experience, or double what many developers plan for."[lxvi]

In addition to reducing costs by eliminating inefficiencies, a clear solution to the current financial insolvency of African utilities – and also to the need to attract much more capital to the sector – would be to increase electricity prices, which in many cases are subsidized as a matter of national policy. However, in practice, it is usually infeasible to raise electricity prices – both economically and politically. As discussed previously, low ability to pay (i.e., low purchasing power) and low willingness to pay for electricity services by average citizens often effectively preclude electricity price.

To achieve more positive outcomes in developing the African electricity sector infrastructure for the 21st Century, it will be essential that many hundreds of billions of dollars – and quite possibly more than a trillion dollars – of capital is attracted to participate. Absent much more capital, advancements in the African electricity sector will simply not happen – and instead more of the same will likely continue to occur.

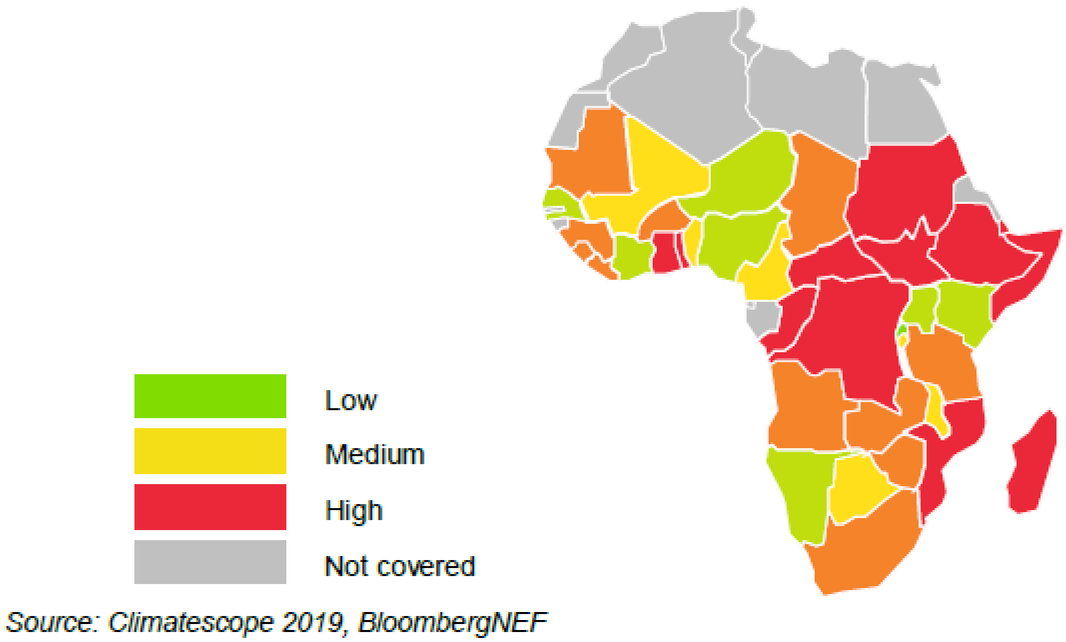
Central to the question of attracting capital is the fundamental issue of risk. Each investment opportunity must produce the expectation to earn a sufficient return to compensate for the risks incurred.

Of course, there are many dimensions of risk associated with any infrastructure investment opportunity. All risks are vital to accurately assess and understand over the asset's multi-decade lifespan, because once deployed, the asset is virtually impossible to relocate to a safe haven if adverse circumstances emerge.

Any investor considering an infrastructure opportunity must assess:

- The creditworthiness of counterparties that will be responsible for revenue payment on the other side of long-term contracts (which, as evidenced in Figure 3-2, is a significant concern in Africa).

Figure 3-2: Risk of Delayed Payment or Non-Payment by Power Off-taker



Source: Sub-Saharan Market Outlook 2020, BloombergNEF, 2020

- The risk that demand or competition will not cause the asset to become uncompetitive or otherwise forced to reduce price.
- The possibility that the asset will fail or not work as anticipated for some technical or operational reason.
- The impact that extreme weather and/or natural disasters might wreak upon the asset and associated impacts on costs and revenues.

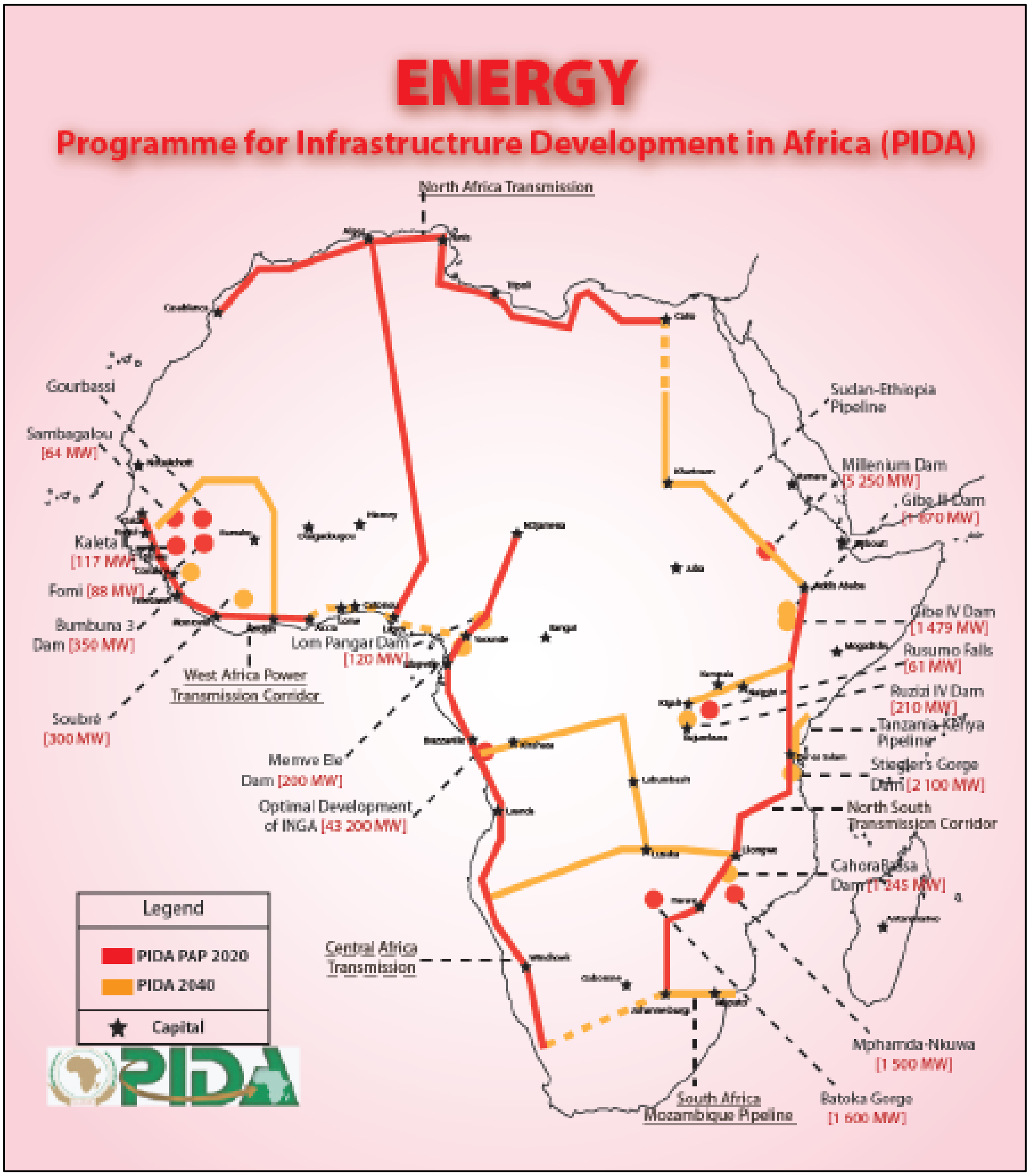
While the above customary risk factors clearly apply to electricity infrastructure projects anywhere in the world, several other risk factors are unique to or especially important in Africa.

Balkanized African Electricity Markets

As discussed previously, electricity transmission systems in Africa are severely underdeveloped, with only a few small interties crossing national boundaries. Consequently, there is limited potential for interregional trade or transfer of electricity, thus foreclosing many generation expansion opportunities (e.g., large hydro projects) that might otherwise be very attractive on most other dimensions. There is also little possibility to find an alternative buyer of power if the first buyer reneges.

With selected exceptions, an electricity sector architecture founded on centralized generation and long-distance transmission projects is not well-suited to the daunting realities of the African continent. To illustrate, consider the high-priority energy infrastructure projects shown on Figure 3-3 targeting a 2020 completion date (with an anticipated $50 billion in aggregate capital requirement) in the African Development Bank's PIDA program.

Figure 3-3: PIDA High-Priority Energy Infrastructure Projects From 2011



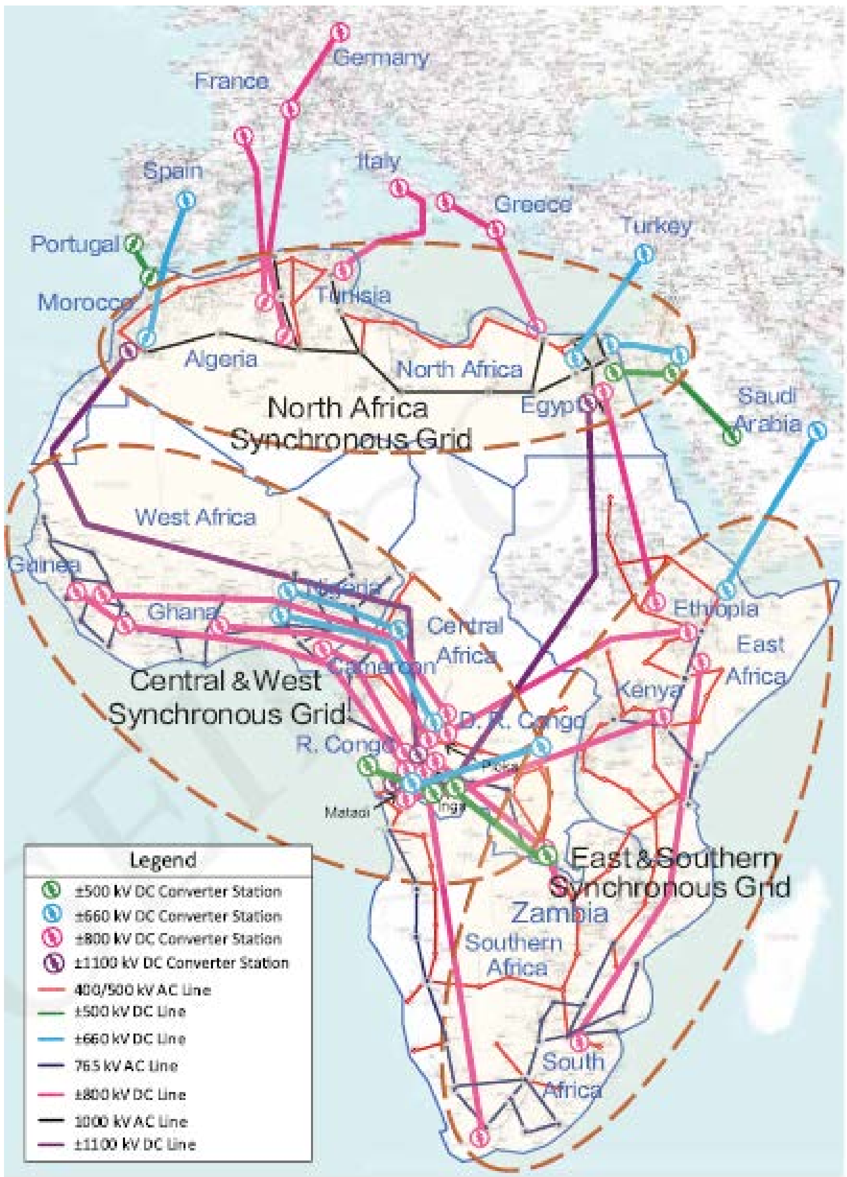
Source: The PIDA Energy Vision, PIDA, *2011*

Of the 316 PIDA projects targeted in 2011 for completion by 2020, just 50% of them had matured to the point of financial close by 2018, and only 18% (57) were operational.[lxvii] Clearly, the majority of these PIDA projects will not be completed on time, despite their priority status. In fact, many won't even be attempted.

The risks associated with projects such as these are large and not easily hedged – and often grossly underestimated by investors accustomed to funding similar projects for many previous decades in more well-developed nations where a large capital asset can be absorbed into the domestic economy in case trade is precluded for some reason. Ineffective multinational coordination and planning is thus a major impediment to investment in African electricity megaprojects.

As a result, ambitious infrastructure plans in Africa often don't come to fruition, or at least are severely delayed or scaled-back. GEIDCO's vision (presented in Figure 3-4) for a pan-African interconnected electricity network by 2050 is clearly subject to these risks.

Figure 3-4: GEIDCO Vision for Pan-African Electricity Grid by 2050



Source: <u>Research on African Energy Interconnection</u>, GEIDCO, 2019

Conversely, an electricity system architecture premised on DER – involving building-blocks of small-scale grids (e.g., nano-grids, micro-grids, mini-grids), usually powered by a combination of solar energy and energy storage – is much less subject to these risks. Therefore, investment opportunities of this type are much more likely to be financeable and consequently more suitable for deployment in many parts of

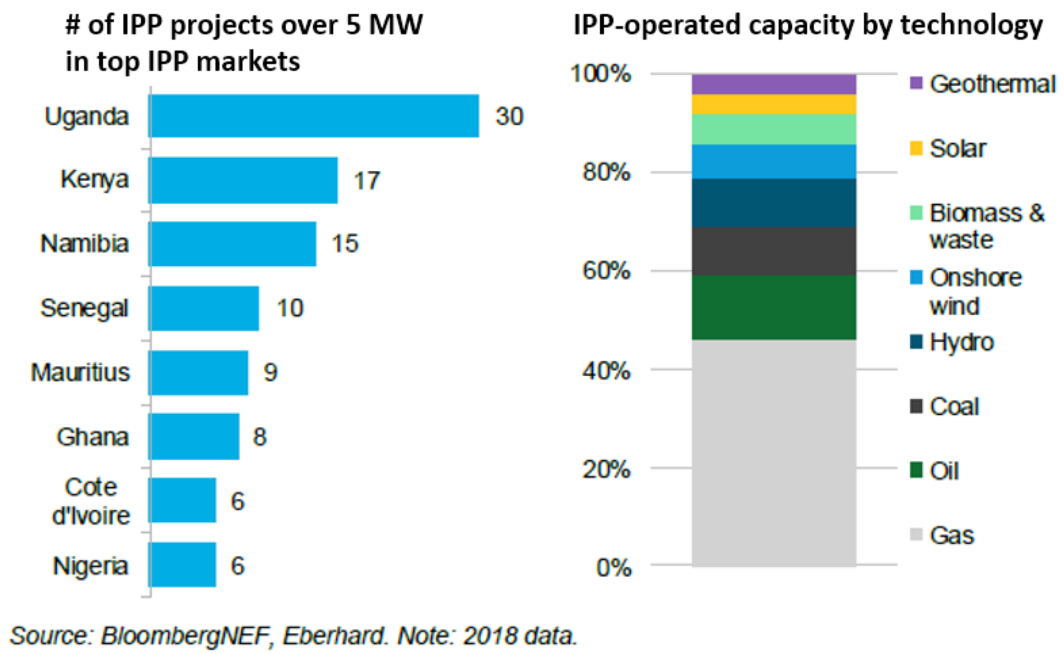
Africa. In contrast to large generation and transmission investment opportunities, DER-based projects are much less inhibited by the lack of electricity network integration across Africa.

Constraints on Private Sector Participation in Electricity

Over the past 30 years, privately-owned and financed independent power producers (IPPs) have emerged as a competitive alternative to regulated (private or state-owned) monopoly utilities for the development and operation of new centralized power generation capacity (both fossil and renewable) in many countries around the world. Where IPPs are a major force in the energy sector, it is possible for investors to participate without having to deal directly with governmental authorities.

Alas, this is generally not the case in Africa. As of 2016, IPPs are a part of the electricity sector in only 18 countries in SSA.[lxviii] As noted in Figure 3-5, Uganda has the most IPP activity.

Figure 3-5: IPP Activity in Sub-Saharan Africa (excluding the Republic of South Africa)



Source: Sub-Saharan Market Outlook 2020, BloombergNEF, 2020

Installed IPP capacity in SSA totals 6.8 GW (or only about 5%) of installed electricity generating capacity.[lxix] Figure 3-4 also shows that about half of the IPP capacity in SSA is gas-fired, with renewables representing about 30%.

The relatively low degree of IPP penetration in Africa results from the fact that, in many African countries, private ownership participation in centralized grid assets is prohibited, as shown in Figure 3-6.

Figure 3-6: Ownership Eligibility for Electricity Infrastructure in African Countries

Most African utilities and regulatory environments don't make it easy for IPPs

Markets	Generation	Transmission	Distribution
Benin, Burkina Faso, Burundi, CAR, Chad, Congo, DR Congo, Eritrea, Ethiopia, Lesotho, Liberia, Malawi, Mozambique, Namibia, Rwanda, Somalia, South Africa, South Sudan, Sudan, Swaziland, Tanzania, Zambia	Public Ownership	Public Ownership	Public Ownership
Angola, Botswana, Djibouti, Gambia, Ghana, Guinea-Bissau, Madagascar, Mauritania, Niger, Senegal, Sierra Leone, South Africa, Togo, Uganda, Zimbabwe	Mixed Public and Private Ownership	Public Ownership	Public Ownership
Equatorial Guinea, Guinea, Kenya, Mali, Sao Tome and Principe	Mixed Public and Private Ownership	Mixed Public and Private Ownership	Mixed Public and Private Ownership
Cameroon	Private Ownership	Public Ownership	Private Ownership
Nigeria	Private Ownership	Mixed Public and Private Ownership	Private Ownership
Côte d'Ivoire, Gabon	Private Ownership	Private Ownership	Private Ownership

Source: "Trends and Forecasts for Africa's Grid-Connected PV Markets", Wood MacKenzie, 2019

Avoiding these ownership restrictions on centralized electricity generation assets, a growing number of entrepreneurial private-sector enterprises focusing on DER opportunities have begun to fill the voids in the African electricity sector. Most of these new entrants are focusing on bringing solutions to rural as-yet unserved customers, so that they need not coordinate with the incumbent utility, and they interface at a much lower level of involvement with governmental authorities.

Numerous Country-Specific Risks

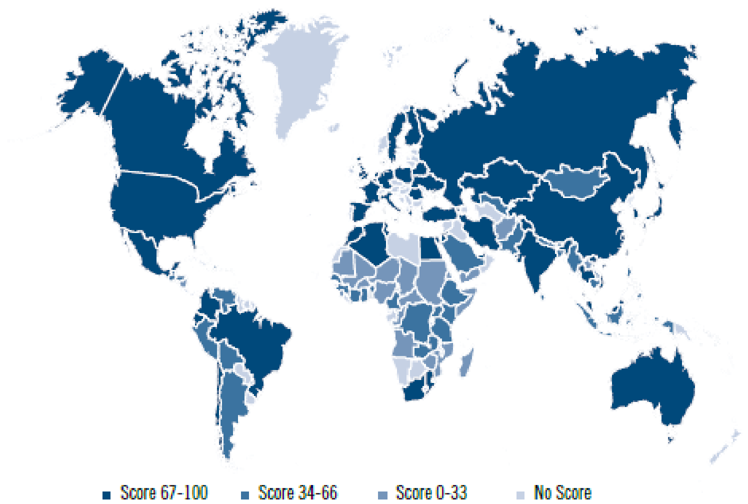
In addition to electricity industry regulatory requirements, there are several dimensions of risk relevant to infrastructure development that are country-specific but expand far beyond the electricity sector – and on most of these dimensions, African countries unfortunately tend to perform poorly:

- Political: Especially for infrastructure assets, investors want a stable government under which long-term investments can be made with confidence. If there is a realistic sense that the government might "nationalize" (i.e., take over) privately-owned assets of strategic interest to the country, such as might occur with electricity infrastructure in the result of a coup or sudden change in power, investment is unlikely. In comparison with other developing regions of the world (such as Latin America), nationalization thankfully has only very rarely occurred in Africa, but this possibility (however remote) is generally attached to any infrastructure investment opportunity in countries where political systems are considered unstable.

- Regulatory/legal: Where governments and political forces are in flux – whether there be separatist movements or weakening dictators – it is usually the case that the underlying regulatory and legal structures will also be unstable. In the case of immovable and illiquid electricity infrastructure assets, prospective investors must gain assurances that key contractual terms (especially pricing) and other "rules of the game" will not be adversely changed on a whim. Moreover, some countries have better policies and institutional environments for promoting electricity advancement. As seen in Figure 3-7, the regulatory frameworks in most

African nations are less conducive for renewable energy development than elsewhere.

Figure 3-7: Low Conduciveness of Regulatory Frameworks for Renewable Energy in Africa



Source: World Bank, 2016, Regulatory Indicators for Sustainable Energy.

Source: Bright Perspectives for Solar Power in Africa?, Institut Montaigne, 2020

Within Africa, Figure 3-8 presents the top countries in BloombergNEF's most recent global Climatescope survey of regulatory policies favorable to electricity sector advancement.

Figure 3-8: Top Rated African Countries for Progressive Regulatory Policies Conducive to Electricity Sector Advancement

Country	Climatescope rank	Energy targets	Auctions or tenders	FiT or premiums	Tax incentives	Debt or equity incentives	Self-generation incentives
Kenya	5						
Zambia	13						
Nigeria	15						
Uganda	18						
Rwanda	25						
South Africa	27						
Tanzania	37						
Namibia	39						
Senegal	42						
Togo	44						

Quality of implementation when available

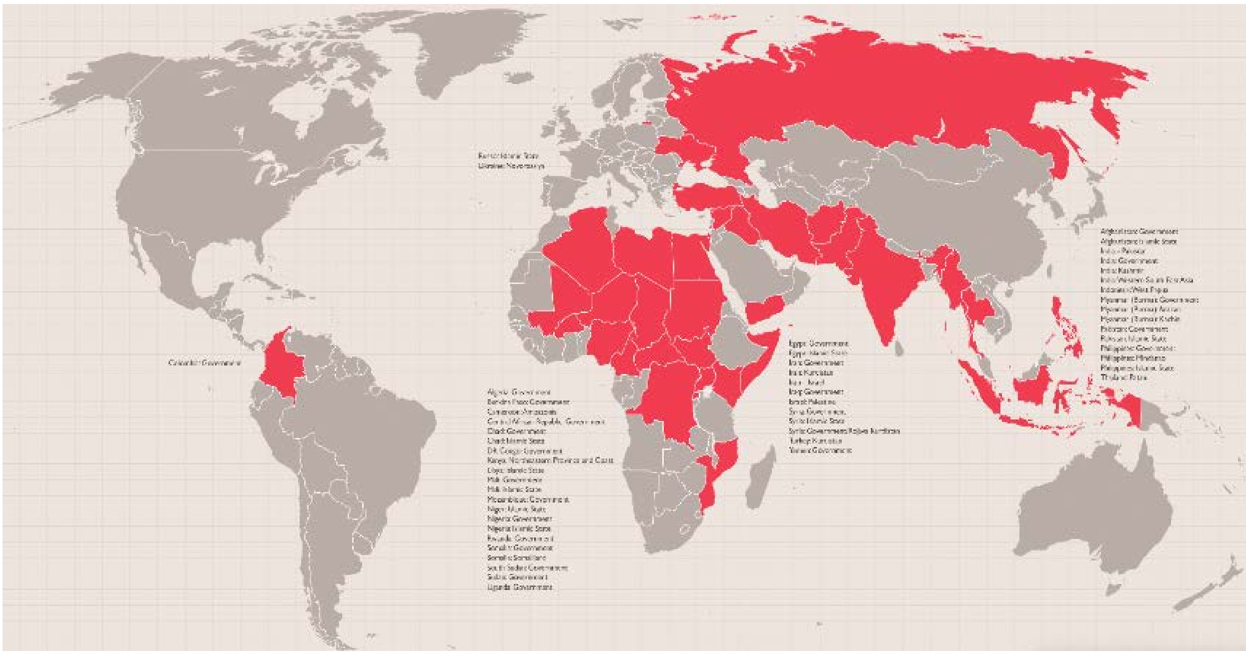
Very good · Good · Average · Somewhat poor · Poor

Source: Climatescope 2019, BloombergNEF. Note: Climatescope is BNEF's annual survey of investment opportunities in renewables in emerging markets

Source: Sub-Saharan Market Outlook 2020, BloombergNEF, 2020

- Conflict: Investors generally don't want to do business where there are wars or tribal conflicts being waged. In addition to the obvious concerns about personal safety, electricity assets can be destroyed for strategic reasons (if not purely out of spite), and operations can easily be disrupted – thereby increasing the risks and costs of doing business. Alas, as seen in Figure 3-9, much of Africa is ridden with conflicts.

Figure 3-9: Active-State Based Conflicts in 2018

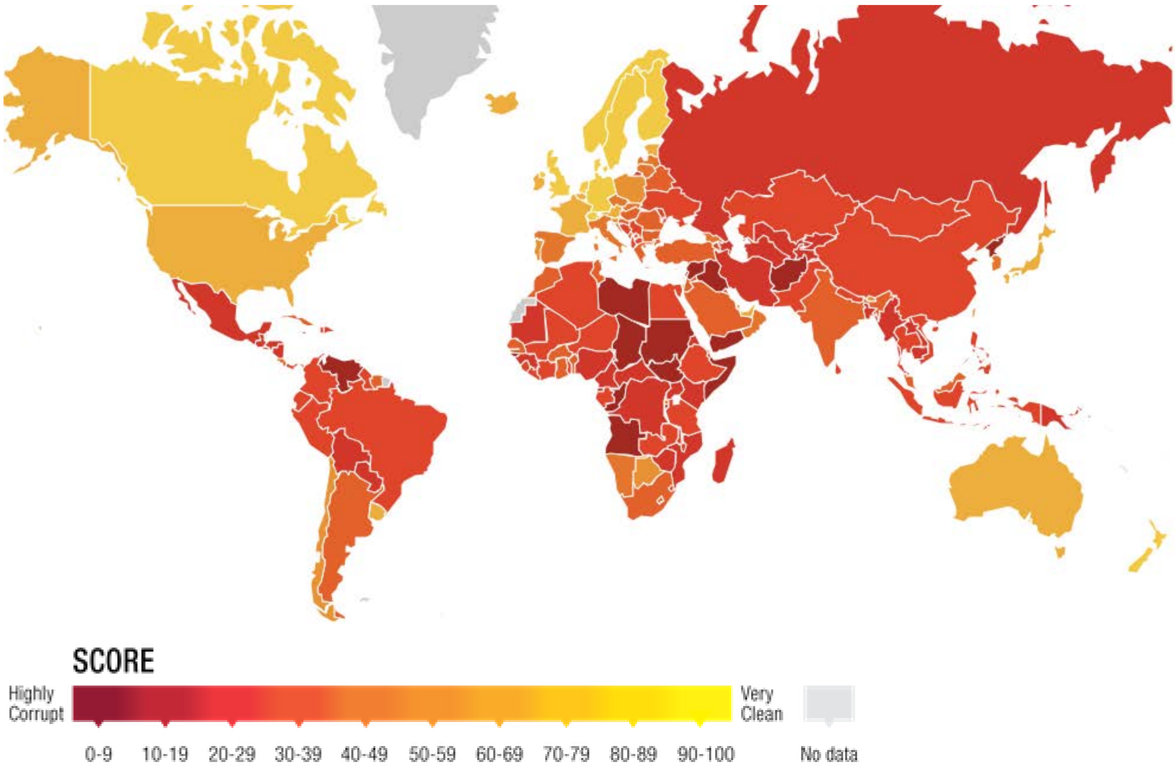


Source: Uppsala Conflict Data Program website

- Currency: Many of the 41 African currencies in circulation are illiquid and rarely employed in international capital-intensive transactions because of the poor state of their underlying economies. For those few currencies that are traded with significant volume in global financial markets, they exhibit much higher volatility compared to other currencies. For example, the South African Rand was recently rated by Bloomberg as the most volatile currency in the world, even though RSA is generally viewed to be one of the wealthiest and most developed countries in Africa.[lxx] Currency illiquidity and volatility of this degree significantly impede the ability to conduct trade and investment. In the case of electricity assets, most equipment (and fuel) purchases are denominated either in US dollars or Euros, thus limiting currency risk. However, since electricity pricing is usually conducted in local currency, revenues associated with investment in African electricity infrastructure are often subject to currency fluctuations that are difficult to hedge, and may cause significant financial imbalances relative to cost structure.

- Corruption: Investors shun places where corruption is rife. Bribery is illegal for US citizens (e.g., the Foreign Corrupt Practices Act) and citizens in many countries – and these anti-corruption laws effectively foreclose many sources of capital from participating where bribes are an expected business practice. Unfortunately, as shown in Figure 3-10, a disproportionate share of the countries deemed the world's most corrupt are found in Africa.

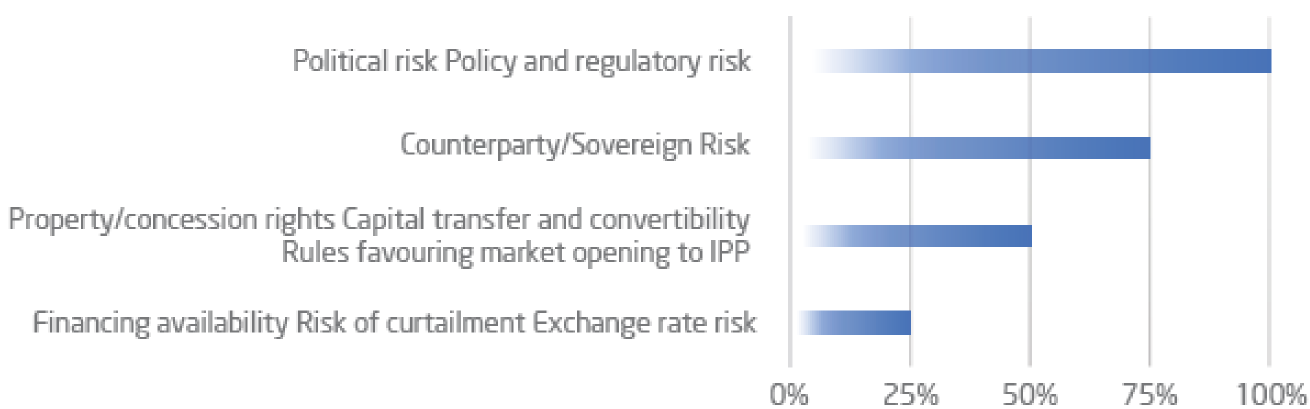
Figure 3-10: Corruption Perceptions Index 2018



Source: Transparency International website

As Figure 3-11 indicates, the global IPP community almost universally sees this disparate set of political, legal and regulatory risks and counterparty/credit risks to be a major concern impeding African electricity sector investment and development.

Figure 3-11: Survey Response Frequency of Most Important Risks As Perceived by IPPs



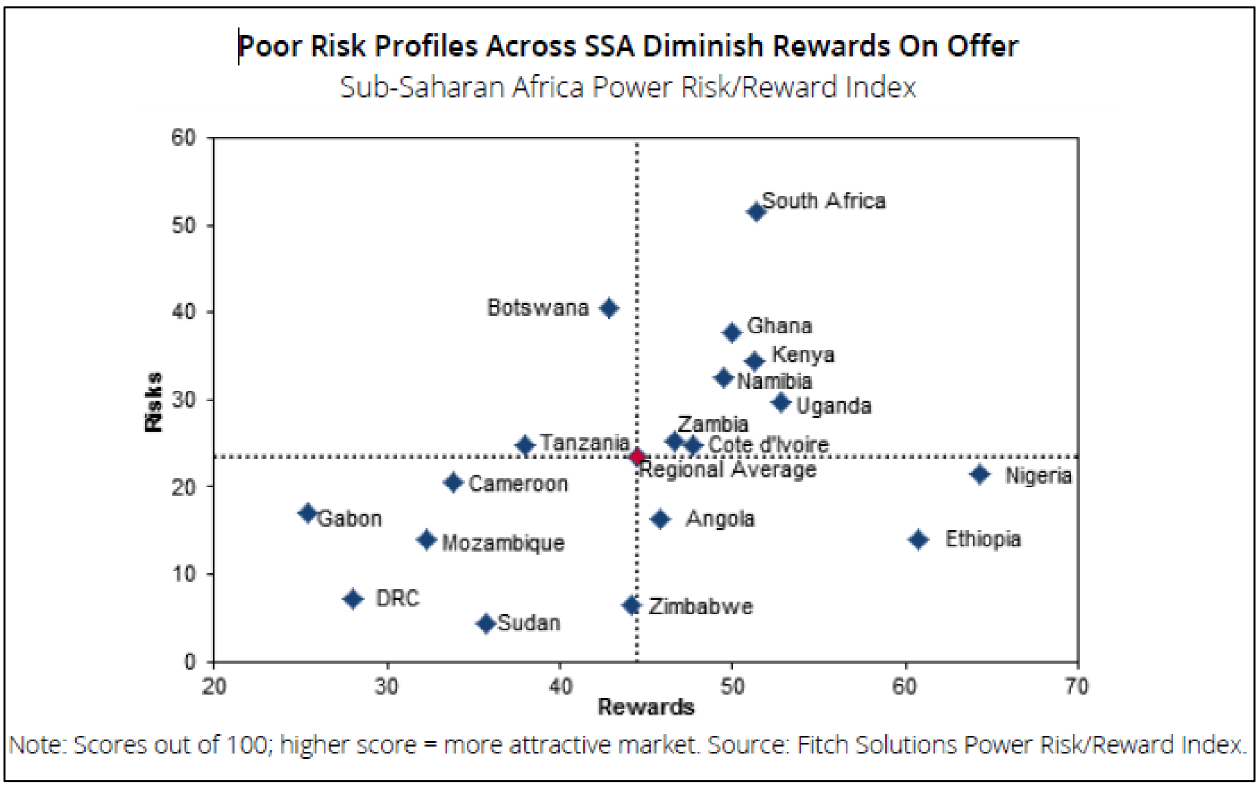
Source: A New Instrument to Foster Large-Scale Renewable Energy Development and Private Investment in Africa, RES4Med&Africa

It should be re-emphasized that all these dimensions of risk exist for infrastructure projects everywhere in the world. However, few places on Earth exhibit these risks to such a high degree as they do in Africa. This makes financing energy infrastructure projects in Africa extremely challenging – even though the needs and the opportunities are so great.

The global infrastructure investment community, and especially participants on the debt side of capital markets, spend considerable time and attention weighing country risks such as those listed above. To help standardize investment decision-making across opportunities, several firms in the financial world develop country-specific indices that distill the various risks into a simple metric.

For example, the ratings agency Fitch recently assessed risk-reward potential for power project development in many countries, and declared SSA "the region with the worst overall Risk profile." Figure 3-12 indicates not only how the SSA countries compare to each other in terms of risks and rewards, but also how they compare to the rest of the world.

Figure 3-12: Most Countries in Sub-Saharan Africa Are Perceived to Have High Risks and Offer Investors Below Average Returns



Source: <u>Sub-Saharan Africa Power RRI: Namibia Climbs Rankings with Renewables Focus</u>, Fitch Solutions, 2019

Figure 3-12 is to be interpreted such that countries in the upper right-hand quadrant represent more attractive markets in which to consider investing, whereas countries in the lower left-hand quadrant represent less attractive destinations for investment. However, even South Africa – the country that Fitch rates as the best performing in SSA – is barely above the world average benchmark (defined as

Rewards = 50, Risks = 50), while the SSA regional average is slightly less rewarding and yet significantly riskier than the world average.

Mitigating Risks Via DER

To mitigate the full spectrum of the above-listed risks as best as possible, selection of electricity access modes needs to closely match local risk profiles. No one single modality of electricity infrastructure will work best for all regions. Across Africa but especially in SSA, a combination of all types of grid systems will likely emerge, from large regional power pools to different scales of distributed systems, even down to a single household unit.

However, as noted throughout the above discussion, DER-based options often imply a lower risk profile than centralized grid asset opportunities.

Since the typical size of the capital outlay is much smaller, the magnitude of risks inherent in DER-based investment opportunities is also much smaller than is the case for large-scale generation and transmission projects. In addition, because of its intrinsically more modular nature, DER-based opportunities are easier to stage in phases. In turn, this implies that construction can be halted if necessary to respond to adverse developments, without completely impairing the ability to generate revenues and cash flows.

Notwithstanding these advantages, the true risks associated with DER-based opportunities nevertheless are prone to being substantially overestimated by potential investors who are unfamiliar with the associated technologies and business models, which still remain somewhat novel relative to the centralized grid equipment utilized extensively over the past 100 years.

Moreover, many financial institutions are accustomed to processing capital in larger volumes, and instead see disincentives in working with smaller-scale investment opportunities such as those offered by DER. In large organizations with extensive bureaucracies relying upon standardized processes and procedures, it is often approximately as costly to evaluate and support a $1 million investment opportunity as a $1 billion investment opportunity. For DER-based grid projects to overcome this disadvantage, it is likely that they will need to be bundled into a larger package for financing – which, as a side benefit, will reduce investment risks via pooling effects.

It is therefore important that financial institutions that fund African electricity infrastructure investments adopt risk-assessment and quantification practices that more accurately characterize both DER and conventional electricity opportunities.

While increasing DER deployment indicates that financial institutions are becoming more familiar with DER's true risk profiles, it is likely that the structural biases against DER persist. For Africa's electricity system to most quickly and efficiently advance, these biases must be fully overcome.

IV: Institutional Efforts to Advance African Electricity

As is typically the case around the world, electricity service in African nations is generally the responsibility of the country's electric utility or utilities. And, as is also the case worldwide, governments also play a large role in national electricity sectors.

Many African governments have developed electricity sector "master plans", with a heavy emphasis on increasing energy access and use of renewable energy sources. Though many of these plans do not provide much detail on implementation strategies, nor the magnitudes and sources of capital requirements to fund implementation, some countries seem to be making more progress than others on electricity sector advancement.

Perhaps the most notable of all is Kenya, which has experienced the greatest progress in expanding energy access over the past decade, with the aim of providing universal electricity access to all Kenyans by 2022.[lxxi]

Other African countries that have set goals to expand electricity access include:

- Ethiopia (100% by 2025)[lxxii]
- Ghana (100% by 2025)[lxxiii]
- Rwanda (100% by 2024)[lxxiv]
- Nigeria (90% by 2030)[lxxv]
- Tanzania (75% by 2033)[lxxvi]

However, as discussed in the prior section of this paper, the high degrees of risk on all relevant dimensions and poor state of virtually every important metric of electricity sector performance across much of Africa (and across almost all of SSA) make clear that electric utilities and governmental agencies in most African countries have generally not been up to the task on their own.

Accordingly, a growing number of institutions, both within Africa and at the global level, have launched initiatives to advance electricity infrastructure development in Africa to help stimulate sustainable growth – both for the electricity sector itself and more broadly for overall economic activity.

African Institutions

- The African Union (AU). The AU was launched in 1963 to secure the sovereignty of newly independent African nations and the African continent as a united body, thereby helping accelerate economic development across the continent. Early stages of AU implementation oversaw the formation of regional economic communities, which have since spawned five power pools spanning the continent, as discussed above. Subsequently, the Pan-African Parliament (PAP) of the AU has authorized several energy policies and laws passed that oversee cross-border energy trade and standardization of infrastructure for improved efficiency. Within the past decade, the AU has issued a 50-year comprehensive action plan in anticipation of its centennial that includes electrification as part of its vision for sustainable and equitable development for the people of Africa.[lxxvii]

- The African Energy Commission (AFREC). In 2008, the AU launched AFREC, which was given the responsibility for overseeing policies, strategies and research for continent-wide integrated resource planning of electricity infrastructure. To date, AFREC has primarily organized capacity-building initiatives to enhance the efficiency of operations in the electricity sectors of member states.

- The African Development Bank (AfDB). The AfDB has been the main source of "local" financing for development projects across Africa. In addition to sourcing capital from international development funds (e.g., the World Bank) that invest in African countries, the AfDB coordinates feasibility studies on new projects and serves as a local source of knowledge and confidence, thereby facilitating other international investors to deploy capital into riskier territories. In 2016, the AfDB launched the New Deal on Energy for Africa, with the objective of catalyzing financing of efforts to achieve universal electricity access on the continent by 2025, including the following specific goals: (1) 160 GW new capacity of on-grid generation, (2) 205 million new connections (130 million via on-grid and 75 million via off-grid), and (3) 150 million households gaining access to clean cooking energy[lxxviii] Between 2016 and 2020, the AfDB committed to invest about $12 billion and leverage up to $50 billion in co-financing for energy projects.[lxxix] The AfDB has also allocated $25 billion towards climate finance from 2020-2025 with its Desert to Power initiative, which aims to mobilize funds towards deploying 10 GW of solar energy by 2025 across the Sahel region to supply electricity to 250 million people.[lxxx] Relative to these goals, actual progress in deploying capital has been more limited: from 2014 through 2017, the AfDB approved an average of $407 million per year for energy access.[lxxxi]

- The Africa Renewable Energy Initiative (AREI). AREI was launched at COP21 in Paris in late 2015 under the mandate of the AU to accelerate and scale up the exploitation of the abundant renewable energy resources in Africa, thereby leapfrogging fossil-based energy generation to the maximum extent practicable. AREI set an initial target of adding 10 GW of new capacity across the continent by 2020 and an additional 300 GW by 2030, with the goal of providing universal access to renewable energy.[lxxxii] AREI has access to $10 billion in funding for Phase 1 of its efforts (ending 2020), which is being administered by the AfDB as an Open Access Global Fund under its Power, Energy, Climate Change and Green Growth Complex.

- The Africa Centre for Energy Policy (ACEP). ACEP is an energy policy think-tank which works to harness the potential of Africa's energy resources (oil, gas and renewable) for accelerated economic and social development. ACEP aims to influence energy sector policies in Africa by providing analysis of energy policy, training, advisory services and policy advocacy for the efficient and transparent management of Africa's energy resources. Notwithstanding the organization's name and its continent-wide ambitions, ACEP appears to focus most of its efforts and activities in Ghana, where the organization is based.

International Intra-Governmental Organizations

- The United Nations (UN). In 2016, the UN established 17 Sustainable Development Goals (SDGs) incorporated in its 2030 Agenda for Sustainable Development. The 7th Goal of the SDGs (SDG7) aims to ensure universal access to affordable, reliable and modern energy services by 2030. To help Africa achieve this energy access goal, the UN has committed to invest $20 billion through the AfDB and mobilize $80 billion in additional resources through public and private partnerships.[lxxxiii] The UN also seeks to invest in small- and medium-scale rural electrification efforts through mechanisms such as the Sustainable Energy Fund for Africa (SEFA), which has sponsored the Africa Renewable Energy Fund (AREF), a pan-African private equity fund managed by Berkeley Energy.

- Sustainable Energy for All (SE4All): An initiative launched under the auspices of the UN, SE4All is a global initiative that facilitates market-creating initiatives to address energy access gaps through commercial approaches driven more by market economics than by subsidies. SE4All also advocates for governments and stakeholders to reach areas where commercial enterprises are unable to operate economically. SE4All focuses its efforts in the 20 high-impact countries (HICs) that account for 80% of the global energy gap, and 15 of these 20 HICs are in Africa.[lxxxiv] Under its geographically focused Electricity for All in Africa initiative, SE4All focuses on policy reform, investment promotion and private sector engagement.[lxxxv]

- The World Bank Group. The World Bank is arguably the most important player in energy infrastructure finance for assets in developing economies around the world. Between 2014 and 2018, the World Bank provided more than $11.5 billion in finance to renewable energy and energy efficiency initiatives worldwide.[lxxxvi] Beyond project finance, some of the development-assistance initiatives undertaken by the World Bank include the Energy Sector Management Assistance Program (ESMAP), within which is housed the African Renewable Energy Access Program, funded by a $29 million grant commitment from the Netherlands.[lxxxvii]

- The International Finance Corporation (IFC). As a member of the World Bank Group, the IFC aims to promote private sector investment in developing countries. Over the past six decades, IFC has leveraged $2.6 billion of its own capital to deliver more than $285 billion in financing for business and opportunities worldwide. In SSA, IFC and its partners have financed over 2.5 GW of generation capacity (including 1 GW of renewable and energy-efficient generation) since fiscal year 2005.[lxxxviii]

- Lighting Africa: Lighting Africa is an initiative by the World Bank and the IFC to act as a market catalyst for deploying off-grid lighting systems across Africa and developing solar lighting standards for African governments. The impact of Lighting Africa has been experienced by 32 million people who have gained basic lighting needs.

- Power Africa. Power Africa is an initiative launched by the U.S. Agency for International Development (USAID) in 2013 with the aim of installing 60 million new electricity connections and bringing 30 GW of new and cleaner power generation online across Africa (notably, lacking any specific target date).[lxxxix] With on-the-ground resources to strengthen local institutional capabilities and de-risk power generation and transmission project opportunities, Power Africa employs a transaction-centered approach to addressing the bottlenecks in project development and investment in the energy sector, thereby facilitating greater investment and success.

- The International Energy Agency (IEA). As an information agency funded by OECD countries, the IEA provides one of the best integrative sources of data and analysis on the status of the African energy sector by country. In particular, the IEA recently released a detailed report on the status and prospects for energy in Africa, Africa Energy Outlook 2019, which has been cited extensively throughout this paper.

- The International Renewable Energy Agency (IRENA). Since its formation in 2011, IRENA's work within Africa has mainly been oriented to boost technical capacity and create conducive investment conditions for renewables, including the development of Renewables Readiness Assessments (RRAs) for countries to assess their readiness to develop and deploy renewable energy.[xc] More specifically, IRENA has been working on regional initiatives such as the Africa Clean Energy Corridor, which aims to accelerate the development of renewable energy potential and cross-border renewable energy trade within the Eastern Africa Power Pool (EAPP) and the Southern African Power Pool (SAPP), while IRENA's West African Clean Energy Corridor aims to support the creation of a regional power market to operate in the Western African Power Pool (WAPP).

- The Global Commission to End Energy Poverty (GCEEP). The GCEEP is an initiative by the Rockefeller Foundation and the Massachusetts Institute of Technology Energy Initiative (MITEI) to define a viable pathway for providing electricity services to underserved households and businesses worldwide. Launched in September 2019, the Commission includes members such as the President of the AfDB, members from the International Renewable Energy Agency, IEA, GOGLA, Power Africa, and several other institutions and organizations. Although the GCEEP's Inception Report acknowledged various bottlenecks spanning the entire electricity value chain in developing countries, the GCEEP identified electricity distribution as the key priority, and consequently developed an Integrative Distribution Framework designed to produce inclusive, permanent and diverse electrification approaches necessary for viably bringing energy access to those who don't currently have it.[xci]

Chinese International Finance Institutions

- The Export-Import Bank of China (China Ex-Im Bank). The China Ex-Im Bank is an agent for executing the international economic policies of the Chinese government. Over the past couple decades, Chinese investment into African economies has significantly increased through bilateral trade, as well as both public and private economic activities. From 2000 through 2018, the China Ex-Im Bank has invested over $25 billion in energy infrastructure in Africa, covering electricity generation, electricity delivery (both transmission and distribution), oil & gas extraction, transportation and refining, and energy efficiency.[xcii]

- China Development Bank (CDB). The CDB provides medium- to long-term financing facilities for infrastructure projects worldwide that serve China's major long-term economic and social development strategies. In Africa, the CDB has provided over $14 billion in capital for energy development since 2000.[xciii]

Dedicated Non-Profit Organizations

- Energy4Impact. Energy4Impact is a UK-based non-profit organization that offers advisory and consultancy services both to the supply and demand side of the value chain in addressing the energy access problem in Africa. To date, Energy4Impact has supported 4,800 businesses to provide 17 million people with energy access and raise $136 million through grants, equity and debt finance.[xciv]

- Energy for Growth Hub: An initiative of the non-profit Center for Global Development, the Energy for Growth Hub aims to address the challenge of 3 billion people living in economies lacking energy to power commercial and industrial (C&I) growth. Energy for Growth Hub believes primary domestic (i.e., household) access to electricity is necessary but insufficient to build competitive economies that sustainably address poverty. Therefore, Energy for Growth Hub is working with experts, global policymakers and African government institutions to share data and analyses necessary to scale climate-friendly C&I energy supply.

- The Africa Minigrid Developers Association (AMDA). Historically, minigrid developers across Africa exerted uncoordinated efforts to advocate for policies that favor their operations. AMDA is the first dedicated trade association of minigrid developers focused on sub-Saharan African emerging markets. Through AMDA, minigrid developers influence policymakers to design policies that advance deployments of privately-owned minigrids.

- The Global Off-Grid Lighting Association (GOGLA). GOGLA serves as an independent, not-for-profit global trade association for the off-grid solar energy industry, with the aim of advancing its member company interests in building sustainable markets for bridging the last mile of electricity access typically unserved by grid electricity. The activities of the association include market intelligence, knowledge sharing, networking, advocacy for policy and investment and promotion of industry standards.[xcv]

As is evident, this is a highly populated landscape of stakeholders seeking to help advance the African electricity sector. Several of these parties – World Bank, AfDB, IFC, UN, AREI, CDB, China Ex-Im Bank – can access significant quantities of committed capital to play a direct role in participating in the finance of infrastructure projects.

(Note that some of these institutions invest in projects through other organizations that are also listed above. Thus, adding the investment magnitudes presented herein would lead to double-counting and hence overstate total investment in African electricity infrastructure.)

Meanwhile, the remaining institutions (with their more limited budgets) act mostly with the aim of institutional capacity-building, advancing more prudent energy policies, and advising on project development.

Even with the many non-profit initiatives to advance the African electricity sector listed above, the discussion in section I of this paper indicates that aggregate capital investment remains insufficient to achieve universal energy access, much less provide high levels of electricity supply across Africa at developed-world standards of reliability and availability.

V: Conclusions and Recommendations for Future Research

Based on this research, several observations relevant to the future development of the African electricity sector become clear:

It Is Neither Possible Nor Prudent to Think About the African Electricity Sector Monolithically

- In general, the electricity sector in North Africa is on par with many developed regions of the world. However, south of the Sahara Desert, in SSA, the situation is dramatically different: the electricity sector in most countries is in dire condition. Even in RSA, where the electricity sector is relatively well-developed, the crisis facing the national utility Eskom is severe, and the nation's economic and energy situation may deteriorate before it begins to improve again.

- Because the situation in each country and region is so different, pan-African conclusions typically must be limited to generalities. (In its recent Africa Energy Outlook 2019 report, the IEA recognized this reality, and conducted "deep-dive" analyses on 11 SSA countries.) High-impact work to advance electricity in Africa is therefore more likely to emerge from the "bottom-up" rather than via a "top-down" approach.

- There is not, and indeed there cannot be, a one-size-fits-all conclusion or solution for optimally building out the African electricity sector. Africa's heterogeneity cannot be overstated or underestimated. The only common attribute across the SSA region is that electricity sector performance is inadequate. How the electricity sector should best be improved will inevitably vary dramatically across Africa.

- Due to limited data availability and quality, it is challenging to undertake robust analyses of many topics related to African electricity sector advancement. While this statement is true at a continental-level, it is especially true for many countries (or subnational regions) across Africa. Accordingly, gathering and improvement of locally relevant data should be a high priority as a precursor to any individual initiative for advancing electricity in Africa.

- Given the paucity of strong national institutions across the continent, those working to advance the African electricity sector are more likely to find localized subnational areas than multinational or even nationwide opportunities where positive impact can be achieved.

Future African Electricity Infrastructure Must Look Different Than Today's

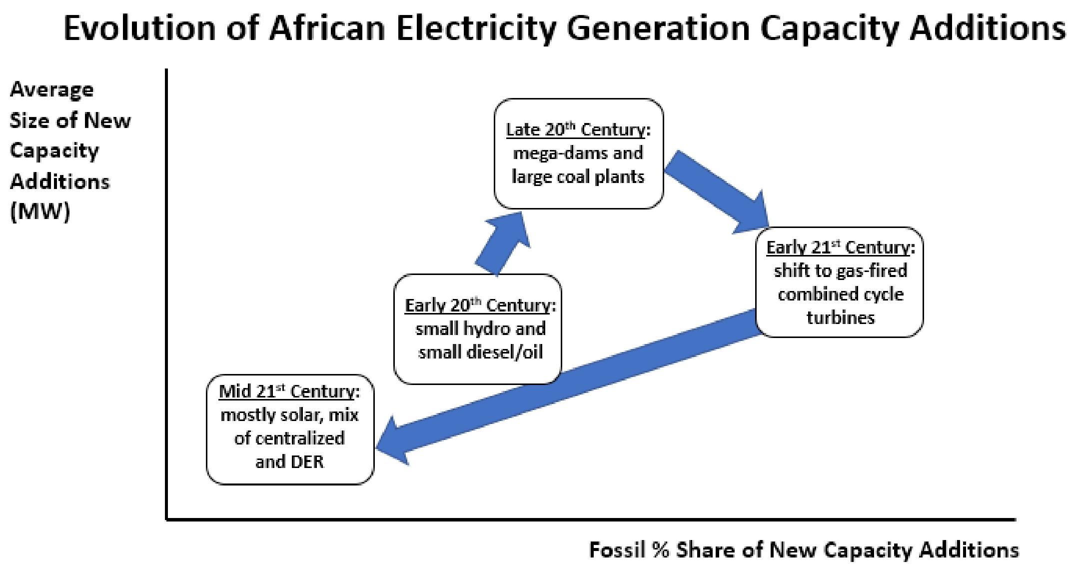
- Whereas the African electricity sector is currently mostly supplied by fossil fuels, renewable energy will represent an ever-increasing share of future growth in capacity. Certainly, some amount of this will be traditional hydro, but wind and (especially) solar deployment will grow rapidly from currently modest levels of installation.

- As the African electricity sector becomes more reliant on renewable energy sources for generation, there will be significant need for investment both in energy storage assets and in improved grid controls to manage intermittency of supplies. Grid reliability is already poor in

Africa, and would further deteriorate if significant additions of solar and wind energy projects were made without matching commitments to upgrade transmission and distribution network flexibility.

- A mix of off-grid DER and centralized grid infrastructure is likely to be the best approach for increasing electricity access across Africa in the most economically viable and environmentally sustainable manner. As a rule of thumb, additions to the centralized grid make sense where the grid currently exists (and is in relatively good shape) to serve urbanized areas with above-average population density. In contrast, DER-based off-grid systems will be the best option where the grid does not currently exist and where population density is low. The "break-point" between the two alternatives – the level of population density such that grid expansion/extension and new microgrid development are approximately equally viable – will be highly situation-specific. As a result, as suggested by Figure 5-1, both the average size of new capacity additions and share of new capacity provided by fossil fuel in the African electricity sector will revert back to its earliest days – except it won't be just small hydro that dominates, but rather PV as the primary renewable resource.

Figure 5-1: After Decades of Increasing Scale and Fossil Intensity, African Electricity Generation Becoming Smaller and More Renewable



Source: ISE original

- Three major trends that must be accounted for when evaluating improvement opportunities in Africa's electricity sector are (1) population growth, (2) growth in purchasing power, and (3) rural-to-urban migration. The geographic distribution of population density and economic activity for Africa in 2050 will likely look very different in many places than is the case today, and it is therefore important to promote electricity infrastructure development that is well-suited for Africa's future rather than designed for its present circumstances.

Investment Requirements Are Massive, But Risks Will Inhibit Capital Attraction

- Under almost any imaginable scenario, because already-large deficits in electricity supply will be exacerbated by expected population growth, the need for investment in additional electricity sector infrastructure across Africa is immense: on the order of $1 trillion in aggregate. On an annual basis, the investment requirement is at least $20 billion per year, and perhaps as much as $100 billion per year. In contrast, the amount of capital that is currently being directed to the sector is no more than $20 billion per year.

- The primary limiting factor for investments in African electricity infrastructure is the availability of financeable projects. The sector is supply-constrained because few infrastructure opportunities are viable based on revenue streams under prevailing conditions (both pricing/tariff levels and volumes of electricity) and consistency of cash flows from creditworthy in-country counterparties. Low levels of economic activity (e.g., GDP per capita) and high levels of perceived (and in many cases, actual) country risk are major inhibitors to attracting investment capital, even if relatively high rates of return are projected.

- When the full spectrum of risks that apply to most places in Africa are properly considered, large-scale electricity infrastructure projects – powerplants larger than 100 MW, long-distance transmission – will increasingly be deemed too risky for the returns that they can offer, especially given the capital-intensity of such projects. Meanwhile, DER-based small-grids with smaller capital requirements will increasingly be recognized as offering superior return prospects for their associated risk profile. This will cause mega-project development in Africa to proportionally decline in importance (except those with compelling renewable resources that support an existing operationally-serviceable urban grid) and off-grid DER-based development to accelerate (especially to enable energy access in rural areas, which characterize the vast majority of the African geography).

Picking Spots to Achieve Maximum Impact

- Given scarcity of resources – both financial and human – relative to the aggregate needs for electricity advancement in Africa, attention should be focused first on countries or regions where tangible improvements are realistically possible. There are many places in Africa where civil unrest, unstable/corrupt government institutions, or lack of electricity sector capabilities are so pronounced that any proactive efforts would unfortunately yield few results. Thus, further work on African electricity should begin with identifying and working with a viable set of constituencies that can productively leverage the outcomes of efforts and investments.

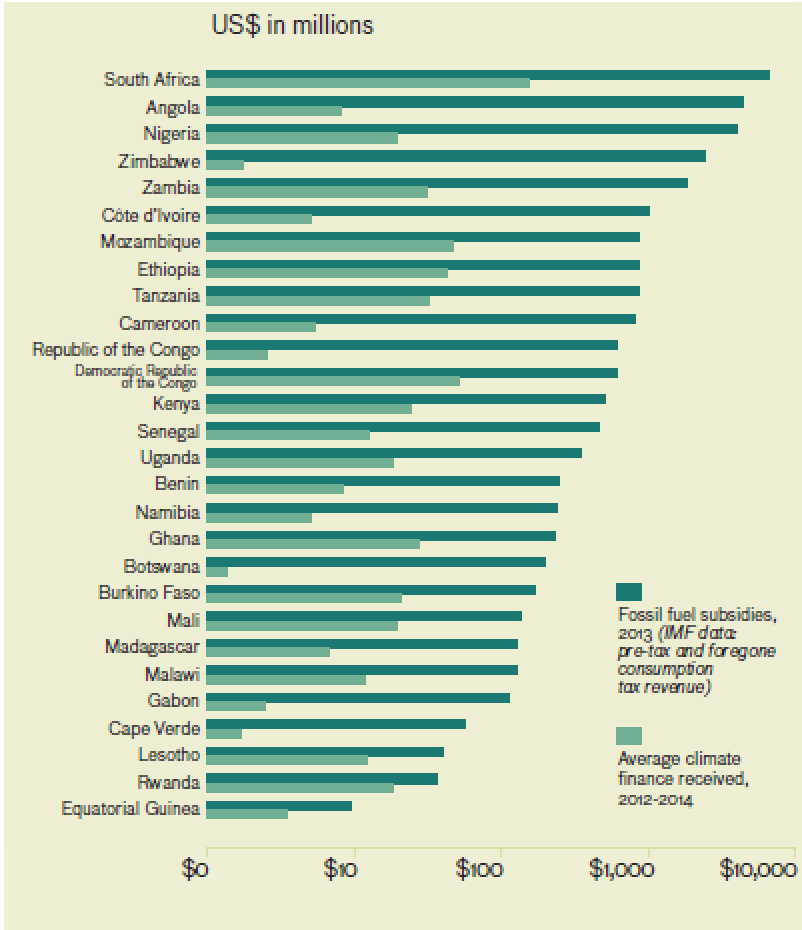
- The biggest single financial crisis facing the African electricity sector today involves the largest utility in SSA: Eskom in RSA. Eskom's insolvency threatens to depress the RSA economy for years, and Eskom's operational challenges are already driving increasing frequency of blackouts. Moreover, since Eskom is effectively the backbone of the Southern African Power Pool (SAPP), the electricity sector in other SAPP nations (Angola, Botswana, Democratic Republic of Congo (DRC), Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe) could also be jeopardized. It is likely that Eskom will undergo a significant restructuring in the coming years; in addition to monitoring for opportunities to assist Eskom directly, stakeholders should also consider support to SAPP and member nations as they cope with the side-effects of what is sure to be a major and painful organizational transformation.

- Since each of them serves many countries, the five power pools spread across Africa might be high-leverage entry points for productive collaboration in advancing the electricity sector on the continent. Success in working effectively with these organizations will require finding and developing strong relationships with trustworthy staff members in positions of authority.

- From an environmental standpoint, the most pressing issue on the planet is climate change, which means curtailing CO_2 emissions from fossil fuel combustion as quickly as possible. On a global scale, Africa is a small contributor of CO_2 emissions, but projected expansion of the electricity sector in a *status quo* manner implies a significant rate of growth in emissions – especially if ambitious energy access targets are to be met – due to the anticipated addition of new fossil-fuel fired capacity (mostly natural gas, but some coal and oil also). To limit and reverse increasing CO_2 emissions from the African electricity sector, it is vital that as much new capacity be built incorporating zero-carbon (i.e., renewable energy) technologies rather than relying upon fossil fuels. In turn, environmental advocates should help African decision-makers identify and pursue economic renewable energy project alternatives to develop in lieu of each planned fossil fuel power plant addition.

- In many urban areas of Africa, local air and noise pollution from diesel backup generators – used as a substitute for unreliable grid power – is a major and growing problem. In addition to emissions, consumers spend significant sums to burn fuel in inefficiently self-supplying their power needs. Targeted initiatives to improve grid electricity supplies in these urban areas, thereby reducing currently high utilization of the many small diesel generators found in most large African cities, could yield sizable economic and health benefits. Meanwhile, the appeal of diesel generators would be reduced by cutting fossil fuel subsidies, which now exceed the magnitude of climate finance activities undertaken in most African countries (as shown in Figure 5-2).

- **Figure 5-2: Fossil Fuel Subsidies Outweigh Climate Finance in Many African Nations**



Source: Whitley, Shelagh and van der Burg, Laurie, Fossil Fuel Subsidy Reform in sub-Saharan Africa: From Rhetoric to Reality, Overseas Development Institute, 2016.

Source: Think Outside the Grid: Africa's Trillion Dollar Energy Opportunity, DBL Partners, 2018

African Electricity Sector Institutions Need Substantial Strengthening

- Most major electricity companies in SSA are functionally insolvent. This is due to a combination of mispriced electricity, inadequate revenue collection (including technical losses and theft), cost mismanagement, insufficient operational/managerial training and skill, and corruption. Therefore, to the extent that these organizations are likely to own/operate (or at least play a heavy role in implementing) new infrastructure, initiatives to effectuate electricity sector improvement in Africa must include concerted and effective efforts to improve utility governance, oversight and operations. To make viable the massive investment opportunities, the global financial community should be especially motivated to ensure that institutional capability-building initiatives proceed in the electricity sector wherever in Africa that they can be productively launched.

- As with the utilities themselves, regulatory institutions in Africa are generally considered to be weak, with only limited resources to provide oversight. Regulatory staff may not be highly trained on global best practices that most encourage electricity sector advancement, particularly for attracting investment in low-carbon generation and other delivery infrastructure. Improving the strength of African regulatory institutions must be a high priority if financially and environmentally sustainable advancement of the electricity sector is to be achieved.

- Cross-border opportunities for joint planning and development of new electricity infrastructure in Africa are significant. For instance, recent research by RMI indicates over $100 billion in cumulative savings could be achieved from 2024 to 2030 in East and West Africa if capacity and transmission planning were better coordinated between nations.[xcvi] However, the mechanisms for implementing a viable project involving multiple countries (e.g., regional power pools) are generally only in early stages of development. To the extent that attractive centralized grid infrastructure development opportunities (generation or transmission) require multinational coordination, strengthening of the relevant power pool(s) may first be required.

- Africa currently lacks an institution analogous to the North American Electric Reliability Council (NERC) for establishing and enforcing consistent standards across the continent for grid planning and operations. If such an institution in Africa existed, it could coordinate between national-level energy authorities to encourage appropriate (and discourage unsound) multinational energy infrastructure development initiatives, make the regional power pools and their associated distribution grids more robust, and therefore improve the ability to attract capital for further expansion projects. AFREC would seem to be a natural candidate to fill this institutional void.

Electricity Sector Advancement Is Part of a Bigger Whole

- Increasing energy access in a fiscally sustainable manner can only be achieved if wealth is created for both infrastructure investors and infrastructure users along the way. An energy access program funded or otherwise supported by subsidies will eventually die under its own weight. As a result, it may be more productive to focus energy access enhancement initiatives on improving electricity service to commercial/industrial/institutional customers – mostly located in urban and peri-urban areas rather than in rural areas – whereby the resulting increases in economic activity (via increased productivity, competitiveness and profitability) can eventually lead regional households to afford their own improvements in electricity service. More broadly, it is important for those in positions of power or influence to see electricity infrastructure expansion as deeply intertwined with – and neither subservient nor precedent to – long-term economic development.

- Opportunities to expand African electricity infrastructure should be considered in tandem with other infrastructure development needs (e.g., drinking water supply, wastewater treatment, telecommunications, etc.) and industrial development activities (e.g., in mining) in order to maximize both cost and capability synergies. Many places in Africa need “all of the above”, and it would be sensible to design infrastructure programs, make investments and establish operations in an integrated and economically optimal fashion.

Never Forget: Advancing the Sector is First and Foremost About Serving the Needs of Africans

- Sensitivity to national and local customs is critical in any initiative. A solution deployed successfully somewhere in Africa will need some customization for successful deployment elsewhere – not just to account for economic differences in the two different geographies, but also for cultural and linguistic factors unique to the new location. Each electricity advancement project brought to fruition needs to "fit" seamlessly within the local community, so that the local population can take emotional ownership of the project's success rather than feel that a project has been thrust upon them – even if well-intended.

- Any initiative to advance the electricity sector in Africa must be consistent with the preferences and beliefs of prospective customers. In addition to undertaking actions that improve customer ability (and willingness) to pay – such as local economic development for wealth-creation purposes and provision of micro-credit to expand access to capital for obtaining electricity-consuming devices – many Africans would benefit from systemic awareness-building on topics that increase the financial viability of electricity service while also improving the lives of those who use electricity. Such topics include (but are not limited to): how using electricity can improve their lives, introduction to electricity devices, payment options, and safety (i.e., how dangerous it is to steal electricity). Additional customer-focused research is likely warranted.

- Common definitions of electricity access should be used with care. Universal access at an entry-level ("Tier 1") is often referenced as a goal of electricity sector development activities. Unquestionably, this degree of energy access is necessary, but remains insufficient: by virtually any standard, Tier 1 levels of electricity consumption are minimal. Therefore, success should not be declared as tranches of population gain Tier 1 access, as this degree of electricity supply remains inadequate for participating in the global economy and achieving a quality of life Westerners take for granted. Rather, the introduction of Tier 1 access should be considered only a first "gateway" step on a path towards affordable electricity availability in quantities that can support true economic advancement – albeit without exacerbating climate change or imposing other environmental burdens.

- It will take decades of concerted investment to eliminate the shortages of electricity generating capacity in most African countries. Until these shortages are resolved, it is difficult to suggest that existing generation assets based on fossil fuels should be retired unless their ongoing costs exceed the costs of replacement zero-carbon (i.e., renewable) alternatives. Africans bear minimal responsibility for human contributions to date towards climate change, and while Africa shouldn't further worsen this increasingly pressing global problem, neither is it equitable that Africa take on disproportionate burden to (for example) retire well-functioning and cost-competitive existing coal-fired generation and thereby worsen electricity shortages. Provided it is in reasonably good operating condition, each installed and operational kilowatt of generating capacity on the grid cannot be spared.

Taking Action

The above points summarize what is known with a high degree of confidence about the current state of and prospects for the African electricity sector. As can be seen, the conclusions are at a high level of generalization. This is because detailed information – which can only be gathered and intelligently interpreted for a specific set of assets or geographic area – is for the most part lacking. In turn, this means that a going-forward research agenda for the African electricity sector must be regionally focused, dictated by which regions are most fruitful for investigation.

Reflecting the above points, interventions – either research or investment – to advance the African electricity sector should be emphasized in countries that both (1) have the greatest needs for electricity sector advancement and (2) exhibit the best prospects for successful advancement. In other words, incremental activities should be focused wherever chances for good traction to be gained for largest positive impact are reasonably high.

As shown in the Section I of this paper, the five countries with the greatest needs for electricity sector advancement (as measured by number of people currently lacking electricity access) are Nigeria, Democratic Republic of the Congo, Ethiopia, Tanzania, and Uganda.

This research refrains from formally ranking countries according to where prospects for success may be the most promising. Conclusions on which countries exhibit the most promise are not offered for the following reasons:

- As the rapid recent deterioration of RSA and its state-owned electricity company Eskom illustrates, the situation facing any country can change (especially to the negative) very swiftly, thus overturning any positive assessment that might be made today.

- Certain readers or stakeholders may have strong reasons (or no choice but) to press for advancement in locations that otherwise would not seem promising – and this research is not intended to deter such laudable efforts.

- Even within countries that would not suggest themselves as particularly promising, there may be local geographic sub-regions wherein many elements of success are present and electricity sector advancement might be viable.

- Across most of Africa, data quality and availability are inadequate to support making judgments on relative merit between countries.

Wherever in Africa additional research is pursued on electricity issues, an initial goal should be to fill location-specific knowledge gaps on topics essential for effective electricity sector development activities. Once a party has identified a specific geographic area in Africa worthy of exploring potential options for electricity sector advancement, a geographically focused research agenda should seek to answer the following questions to the next level of detail:

- How can the current centralized grid be better leveraged?
    - What operational improvements (both in generation and in T&D) can reduce costs and losses, and improve reliability, quality and availability of electricity supply?

    - How can the use of diesel backup generators be minimized?
    - When will the cost of operating existing fossil-fired power generation become more expensive than replacing with alternatives?
    - What can be done to ensure that tariffs accurately reflect costs and send proper price signals to induce appropriate investment and consumption decisions?
    - What can be done to improve customer willingness and ability to pay for electricity service?
    - What programs can be implemented effectively and efficiently to truly improve the institutional capabilities of utilities and overseeing authorities?

- What should the expansion plan be for the centralized grid?
    - What is a robust (i.e., scenario-based) renewables-heavy future generation resource plan?
    - What new fossil-fired power plants are planned, and what renewable energy options might exist as better alternatives?
    - How can transnational power pools be better leveraged?
    - What new transmission development opportunities (including cross-border) are truly worthy of pursuit?
    - Which distribution upgrades and expansion plans (i.e., to bring service to new areas) should be prioritized?
    - What grid flexibility investments (energy storage, controls) will be necessary?

- How should microgrids complement the centralized grid?
    - What can/should be done to strengthen the progress/success of existing microgrids?
    - Under what conditions, where specifically, and in what order should new microgrids be pursued?
    - What is a realistic trajectory for more off-grid customers more quickly to obtain energy access in increasing tiers?
    - Under what conditions should microgrids be connected to the centralized grid to enable more extensive volumetric growth in usage?
    - What standardized technical design and business model is optimal to fit the climate and culture?
    - How can subsidies and below-market capital sources be minimized for microgrids?
    - What local economic development and entrepreneurship roles should microgrids play for the communities they serve?

In most places across the continent of Africa, the answers to these questions are generally not well understood. Often, the underlying information isn't publicly accessible (or doesn't exist at all), and where the data might exist, the analysis to transform it into insight hasn't been undertaken.

Given that the available resources will be limited relative to the size of the continent-wide need or opportunity, parties seeking to bring power and progress to Africa should:

- Focus most diligently on locales with both the greatest needs for electricity improvement and the greatest potential for success in implementing change,

- Forge strong collaborations with earnest counterparties in these environments to maximize the chances for long-term viability of the investments that they make, and
- Undertake the above research agenda to fill in knowledge gaps and thereby gain a much more well-informed perspective of the true opportunities and risks.

List of Acronyms and Abbreviations

AC: (1) Alternating current or (2) Africa Case Scenario (from IEA Africa Energy Outlook 2019)

ACEP: Africa Centre for Energy Policy

AfDB: African Development Bank

AFREC: African Energy Commission

AMDA: Africa Minigrid Developers Association

AREF: Africa Renewable Energy Fund

AREI: Africa Renewable Energy Initiative

AU: African Union

BBC: British Broadcasting Company

C&I: Commercial and industrial

CAPP: Central African Power Pool

CDB: China Development Bank

CO_2: Carbon dioxide

COMELEC: Comité Maghrébin de l'Electricité (Northern African Power Pool)

COP21: Council of Parties 21 (2015 Paris Climate Conference)

DC: Direct current

DER: Distributed energy resources

DRC: Democratic Republic of Congo

EAPP: Eastern African Power Pool

EARS: East Africa Rift System

EPC: Engineering/procurement/contracting

ESMAP: Energy Sector Management Assistance Program (of the World Bank)

EU: European Union

Ex-Im: Export-Import

GCEEP: Global Commission to End Energy Poverty

GEIDCO: Global Energy Interconnection and Development Coordination Organization

GOGLA: Global Off-Grid Lighting Association

GW: Gigawatts

GWh: Gigawatt-hours

HIC: High-Impact Country

IEA: International Energy Agency

IFC: International Finance Corporation

IHA: International Hydropower Association

IPP: Independent power producer

ISE: Institute for Sustainable Energy (of Boston University)

IRENA: International Renewable Energy Agency

kW: Kilowatts

kWh: Kilowatt-hours

LCOE: Levelized cost of energy

LED: Light-emitting diode

LNG: Liquified natural gas

MIT: Massachusetts Institute of Technology

MITEI: MIT Energy Initiative

MOU: Memorandum of Understanding

Mt: Megatonne (million metric tons)

mtpa: million tonnes per annum (of LNG)

MW: Megawatts

MWh: Megawatt-hours

NERC: North American Electric Reliability Council

NGO: Non-governmental organization

OECD: Organisation for Economic Cooperation and Development

PAP: Pan-African Parliament

PAYG: Pay-As-You-Go

PIDA: Programme for Infrastructure Development in Africa (of the AfDB)

PBL: Netherlands Environmental Assessment Agency

PPA: Power purchase agreement

PV: Photovoltaics

RMI: Rocky Mountain Institute

RRA: Renewables Readiness Assessment

RSA: Republic of South Africa

SAPP: Southern African Power Pool

SDG: Sustainability Development Goal

SDG7: Sustainability Development Goal 7

SE4All: Sustainable Energy For All

SEFA: Sustainable Energy Fund for Africa

SHS: Solar home system

SSA: Sub-Saharan Africa

STEPS: Stated Policies Scenario (from IEA Africa Energy Outlook 2019)

T&D: Transmission and distribution

tcf: trillion cubic feet (of natural gas)

TW: Terawatts

TWh: Terawatt-hours

UN: United Nations

UNEP: United Nations Environment Programme

US: United States

USAID: United States Agency for International Development

W: Watts

WAPP: West African Power Pool

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