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Off-Grid Electricity Development in Africa: Uncertainties and Potential Implications for Electric Power Markets

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The International Energy Outlook 2020 (IEO2020) is in the second year of the U.S. Energy Information Administration's (EIA) two year IEO development cycle. In the second year of the cycle, EIA keeps the same IEO2019 Reference case, but uses our modeling tools to dive deep into areas of uncertainty. We use largely the same models, the same economic assumptions, and the same input oil prices, but look at specific elements or assumptions. IEO2020 focuses on electricity markets. Limited tables, focusing on the cases discussed in three Issue in Focus papers, are released this year.

Because IEO2020 is based on the IEO2019 modeling platform, and because it focuses on long-term electricity market dynamics, it does not include the impacts of the novel coronavirus. Discussions of IEO2020 results focus on longer-term market dynamics beginning in 2025 or later. The Annual Energy Outlook 2021 (AEO2021) and IEO2021 will both feature additional analysis of effects of COVID-19 on energy markets.

Introduction

Despite a large and rapidly growing population, the U.S. Energy Information Administration (EIA) expects electricity consumption in Africa to remain a relatively small share of global totals through 2050.[1] Relatively low consumption, in part, results from the limited reach of central grid power in rural areas and the unreliability of central grid power in urban areas. Declining costs of solar photovoltaic development and expanding use of mini-grid distribution systems have made these technologies possible options for further development of electricity infrastructure in Africa. [2,3] Use of such options could shift Africa's power generation mix away from the coal and natural gas currently used in the central grid toward a greater contribution by renewable resources to meet demand.

In this paper, EIA identifies factors that could influence the development of mini-grid and other off-grid[4] electricity generating technologies in Africa and demonstrates the effects of wide-scale deployment of these technologies on the total generation fuel mix. This analysis shows that off-grid generation has the potential to significantly shift the generation mix in Africa in the long term. If the estimated unserved electricity demand in Africa were satisfied exclusively by expanding the centralized grid, our analysis shows more growth in both coal- and natural gas-fired generation. If unserved demand were met

[1] EIA, *International Energy Outlook* 2019 (IEO2019)

[2] Bloomberg NEF, Solar for Businesses in Sub-Saharan Africa, 2019

[3] A mini-grid is an isolated, small-scale distribution network (typically operating less than 11 kilovolts) that provides power to a localized group of customers and produces electricity from small generators, potentially coupled with an energy storage system. *Mini Grids: Bringing Low-Cost, Timely Electricity to the Rural Poor*. 2019. World Bank.

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode. *DOE Microgrid Workshop Report.* 2011. Pg. 1

[4] Off-grid applications include distributed generation types, such as solar lights, solar home systems, diesel self-generation, and mini-grids.

instead by off-grid resources, it could shift the generation mix toward non-hydroelectric renewable generation sources.

The electricity market in Africa

Electricity consumption in Africa, on both a total and a per-person basis, is relatively low, but has tremendous growth potential. In 2019, with a population of 1.3 billion people, Africa had nearly four times the population of the United States, and Africa's population is expected to grow to 2.4 billion by 2050.[5] Yet, with an average net electricity generation of about 600 kilowatthours (kWh) per person per year—less than 6% of the United States average per person—Africa generated only 804 terawatthours (TWh) of net electricity in 2019, 20% of the United States total that year.

This analysis considers the electricity market in Africa as comprising two distinct regions, denoted here as *Africa North* and *Africa South* (Figure 1). [6] Africa's transmission networks are divided, split between a largely coastal system in Africa North along the Mediterranean Sea and a nearly continent-long system linking the West, Central, and Southern power pools among the countries bordering the Atlantic Ocean to the southern tip of Africa.[7]

Most of Africa's natural gas-fired generating capacity is located in Africa North, where most of the natural gas resources in the continent are located (Table 1). Most of the continent's coal-fired generating capacity is located in Africa South. The Sahara Desert creates a barrier to shipping fuels and transmitting electricity on the continent. The two fuel supplies are not easily transported across the continent because of infrastructure limitations, and electricity is not easily transmitted because of the lack of interconnection between the two regions.

Table 1. 2019 coal and natural gas-fired generating capacity (gigawatts)

	Coal	Natural gas
Africa North	4.2	73.5
Africa South	43.3	17.8

[5] EIA, *International Energy Outlook* 2019 (IEO2019)

[6] For this analysis, the region of Africa North consists of the following 12 countries: the 5 bordering the Mediterranean Sea (Algeria, Egypt, Libya, Morocco, and Tunisia) and their immediate neighbors Chad, Eritrea, Mali, Mauritania, Niger, Sudan, and Western Sahara. The Africa South region consists of all the remaining countries on the continent.

[7] As of 2019, the East Africa power pool, established in 2005, is not interconnected with the remaining pools. A map of the power pools is available from the Global Energy Network Institute.

Figure 1. Africa North and Africa South regions and existing transmission[8]

Source: EIA, International Energy Outlook 2020, World Bank Electricity Transmission and Distribution data set

The regions also serve different demographics; although most of the population of Africa North lies in a relatively high-density region near the coast, typical population densities of Africa South are much lower. Among the 12 countries of Africa North, 5 (Egypt, Algeria, Libya, Morocco, and Tunisia) have a relatively urban population (56% of the population live in urban areas in these five countries, compared with 31% for the remaining countries in Africa North). These countries also have the highest connectivity[9] and the most developed electricity transmission and distribution infrastructure in Africa, with interconnections to the Middle East and to Europe.[10] With more than 60% of the Africa South population living in rural areas, traditional transmission and distribution systems are often more costly to develop on a per customer basis.

[8] Transmission data from the World Bank Electricity Transmission and Distribution data set, 2017. The authors caution: "This data is incomplete and the sources vary by country and region. It should not be used to make comparisons about the extent of grid coverage between countries or areas." World Bank: Data Catalog: Africa Infrastructure Country Diagnostic (various sources)

[9] An electric connection is a direct path for between two points in a circuit. In this report, *connectivity* is defined as the extent of regional grid interconnection.

[10] Updated Regional Power Status In Africa Power Pools Report. The Infrastructure Consortium for Africa

Although comprehensive data on the share of off-grid electricity in Africa South are limited, a recent World Bank Group Energy Management Assistance Program Multi-Tier Framework for Energy study of Ethiopia, Kenya, and Rwanda shows that 3% of urban electricity access is off-grid and 49% of rural electricity access is off-grid.[11] Plans for expanded access to electricity in the region have relied on the addition of off-grid applications, such as solar lights, solar home systems, and mini-grids. Generally, it is less costly to install these systems than to build out the transmission and distribution system to many remote areas with potentially low demand for electricity. Off-grid technologies are less competitive in Africa North, whose population has greater access to existing well-connected transmission and distribution systems.

As of 2017, 79% of the population in Africa North had access to electricity, but only 48% of the Africa South population had access.[12] As a result, electricity consumption per capita in Africa South is lower, at 350 kWh per person per year, which is one –third of the level in Africa North (1,000 kWh per person per year) and one-tenth of the worldwide average electricity consumption per person (3,200 kWh per person per year).

Options for expanding electricity access

Africa South has three basic options to expand electricity access:

1. Connect customers to the existing grid through grid extension[13] and densification.[14]
2. Set up localized distribution systems (micro-grid or mini-grid) linked to either a renewable or diesel generation source.
3. Install stand-alone generation sources, powered either by renewable sources or by diesel generators.

These options imply cost trade-offs between lower power generation costs of central station generating units with a higher cost of transmission and distribution networks versus the relatively higher cost of power from decentralized generating units with lower cost of distribution networks. For example, grid expansion requires investment in the transmission network (such as, costs for high- or medium-voltage lines, transformers, and household connections), which is a function of distance, terrain topology, and

[11] Multi-Tier Framework for Energy, 2018, World Bank referenced in 2019 Tracking SDG7, World Bank, 2019.

[12] In the context of this paper, *electrification*, or electricity access, is defined as the ability to acquire electricity, whether on-grid or off-grid, whether provided by a central utility, a private company, or the users themselves, and whether generated from large, central power stations, local mini-grids, or small stand-alone generators, and regardless of the source of power. The World Bank provides a related quantitative definition of electrification, defined as the electricity access with multiple dimensions. To be meaningful for households, productive enterprises, and community facilities, the energy supply supporting that access must have a number of attributes: it must be adequate in quantity, available when needed, of good quality, reliable, convenient, affordable, legal, healthy, and safe. *Beyond Connections Energy Access Redefined*. 2015. World Bank. pg. 3

[13] Grid extension: the extension of the medium voltage (MV) and low voltage (LV) distribution grid to connect households or other customers to the central energy supply system. This central system includes power generation, transmission, and distribution. *Grid Extension.* Science Direct.

[14] Grid densification: New grid connection especially for households living close to the local utility grid but who are not yet connected. Grid densification is divided into two categories: (1) grid densification by transformation, if villages that are near an existing transmission line connection can be achieved through a change of voltage level, and (2) densification through an existing low-voltage distribution grid, by the connection of additional households. Energypedia

other factors. By comparison, establishment of a mini- or micro-grid requires potentially smaller capital expenditures, including lower cost distribution systems, connections to distributed generators, and control systems. For a representative lower energy-intensive system in a less densely populated area, costs to extend the central transmission grid can be as much as twice the cost of a micro-grid system.[15] On the other hand, for a higher energy intensive system in a more densely populated area, grid connection costs can be as much as one-third less than the costs of a micro-grid system. Stand-alone generation has the lowest initial capital costs of the three options above but scales least efficiently.

Electricity demand concentration

Aside from initial capital cost, electricity demand concentration (demand per area) is the biggest factor when choosing options for adding electric service.

Two additional cost drivers affect the relative economics of the technology options. Electricity consumption is the sum of the energy consumed for personal and commercial activities, which EIA considers, in this analysis, to be composed of a scale and an intensity. For personal consumption, the scale is the population of the area, and the intensity is related to the expected service level. For commercial activities, the scale is the amount of economic activity, and the intensity is related to the composition of those activities.

Population density: Expanding access to the grid involves significant investment in electricity transmission and distribution infrastructure to connect remote areas to the centralized grid. In general, low population density and correspondingly low energy demand support off-grid options, such as stand-alone generators or mini-grids, because of lower requirements to invest in transmission and distribution. On the other hand, higher population density and level of demand favor grid connection because the associated higher levels of electricity demand mean a greater ability to recover transmission costs.

As a metric, lower population density suggests smaller population centers separated by larger distances between centers. The smaller population centers might be too far away from the central grid to run a transmission line to, but they might be good candidates for mini-grids. Rural areas without population centers might be better candidates for stand-alone generation.

Level of service: In the residential sector, electricity demand is related to how heavily a population consumes electricity services. For example, the World Bank has defined five tiers of demand,[16] which can be used to categorize the intensity of electrical service (Table 2).

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[15] Sustainable Energy Access for All: Initial tools to compare technology options and costs- F. Nerini, KTH Royal Institute of Technology, 2016 pg. 31

[16] Demand targets: In World Bank electricity access studies, the level of demand is defined in progressive tiers of access (from Tier 1 to Tier 5), beginning with small appliances and expanding to the most electricity-intensive uses, as indicated in Table 2 below.

Table 2. Multi-tier approach to measuring access to electric services—residential[17]

Tier	Types of appliances	Examples
Tier 1	Very low power	Task light and phone charging or a radio
Tier 2	Low power	General lighting, a television, or a fan
Tier 3	Medium power	Tier 2 plus a printer, refrigerator, freezer, or washer
Tier 4	High power	Tier 3 plus an iron, hair dryer, toaster, or microwave
Tier 5	Very high power	Tier 4 plus an air conditioner, water heater, or electric cooking

As demand growth advances to higher tier levels of consumption, stand-alone generating options become costlier compared with other solutions. Higher energy requirements necessitate increases in the load carrying capability of the electric transmission and distribution systems, which make the transmission and distribution system investment associated with grid expansion more economical on a unit cost ($/kW) basis by spreading the fixed costs of those investment across the levels of demand for electric transmission and distribution services.[18]

Economic activity: For businesses, energy demand is related to economic activity. Assuming a fixed energy intensity (British thermal units per dollar), higher levels of economic activity are associated with greater electricity demand, which in turn strengthens the case for a central grid.[19]

The geographic distribution of the economic activity matters. The measure gross domestic product (GDP) density indicates the economic activity of an area, and it can be used to identify potential candidates for particular electrification strategies. For instance, commercial centers in the middle of a larger rural area might be good candidates for micro-grids, but more diffuse distributions of commercial activity might be more suitable for stand-alone generation, even if the total areas and GDPs of the two examples are the same.

Composition of economic activity: Given a fixed level of economic activity, increasing the electricity intensity of the underlying activities (switching methods of production to include more machinery, for example) also strengthens the case for a central grid. Traditionally, energy intensity rises as a country moves from an agrarian economy to a more industrialized one, and then it can flatten as more economic growth comes from a service sector.[20]

[17] International Energy Agency and the World Bank. 2015. "Sustainable Energy for All 2015 : Progress Towards Sustainable Energy" (June). World Bank, Washington, D.C. Doi: 10.1596/978-1-4648-0690-2 License: Creative Commons Attribution CC BY 3.0 IGO

[18] Level of service also relates to service reliability. Compared with other emerging markets, Africa South electric systems tend to report relatively high outage rates, resulting in significant uncertainty for centralized grid customers. As a result, some customers install backup generators, generally fueled by diesel oil. Lack of confidence in central grids can influence the choice favoring stand-alone systems.

[19] The relationship between economic activity and electricity demand is synergistic, rather than causal. Electrification can support economic activity, and economic activity can drive electrification. Although this section addresses how economic activity can support electrification choices, those electrification choices can drive additional economic growths.

[20] IEO2019 Issue in Focus. Alternative industrial sector outcomes in India: India's energy use could be much higher. EIA.

Additional drivers

Operating costs: Besides the capital costs associated with the investment in electric generators and grid systems, operating costs also need to be taken into account. Historically, off-grid systems have been expensive to operate because stand-alone generators are typically less efficient, higher heat rate units that consume relatively more expensive diesel fuel. As more solar photovoltaic and battery storage systems are deployed, however, this relationship may change.

Among the off-grid options, a trade-off occurs between diesel generator operating costs and renewable generation and storage capital costs. At higher levels of diesel fuel costs, given a fixed set of capital costs, renewables can become economically attractive. Similarly, where diesel generators run more frequently as a result of unreliable central power grids, higher operating costs may decrease their competitiveness compared with renewable sources.

Other factors: A number of other factors influence the choice among electrification options:

- The policy commitment to expanding electricity access and the nature of those commitments Where governments have created programs to support particular forms of access, they can influence the choice of technologies.
- The level of private investment, which can be a significant factor in supporting both mini-grid and stand-alone project development.

Cases

The IEO2020 analysis is based on the IEO2019 modeling platform, and the electricity supply component (the International Electricity Market Model, or IEMM) includes updated renewables targets, revised costs for certain fuel-region combinations, an updated geographic representation of Africa, and updated representations of market dynamics in select regions.[21] Because IEO2020 is based on the IEO2019 modeling platform and because it focuses on long-term electricity market dynamics, it does not include the impacts of the novel coronavirus. We used a modified IEO2019 platform to develop the Comparative Reference case (CRC).[22] We analyzed additional cases to demonstrate how refining the regionality of Africa in IEMM would affect EIA's projections and to bound the potential off-grid generation in Africa South (Table 3).

[21] EIA's international modeling system, WEPS, for IEO2020 also includes a simplified representation of the Global Hydrocarbon Supply Module (GHySMo).

[22] The Comparative Reference case assumes that electricity demand produced by the end-use sectors will be met by marketed electricity from the central grid. In many regions of the world, and in particular Africa, this representation oversimplifies the reality. There is also grid-proximate, supplemental generation (for example, diesel generators), which can be significant because of chronic grid reliability issues, and off-grid electricity generation. Although WEPS captures the diesel fuel consumed in off-grid, stand-alone generators in the buildings sector, it does not capture its consumption as electricity.

Table 3. Key assumption changes for Reference and alternative off-grid development cases

Case name	Analysis	Regions in Africa	Electrification in 2030	Africa South incremental demand met by?
Single Region case	Regionality case	One	52%	None
Comparative Reference case	Regionality case	Two	52%	None
Maximum Grid Expansion case	Grid Development case	Two	100%	Central grid
Maximum Off-Grid case	Grid Development case	Two	100%	Solar photovoltaic off-grid

Source: EIA, International Energy Outlook 2020.

Regionality cases

For previous *International Energy Outlook*s, EIA modeled Africa as a single region, effectively allowing demand for electricity in Africa to be satisfied by electric generators anywhere on the continent. For IEO2020, to more accurately reflect the underlying north/south structure of Africa's electricity infrastructure, EIA created the Comparative Reference case where we split the single region *Africa* in the *World Energy Projection System* (WEPS) into the IEMM regions of *Africa North* and *Africa South*. As discussed, these regions better represent natural gas and coal market constraints as opposed to modeling a single Africa region.

The WEPS demand modules still calculate electricity demand for the single Africa region.[23] To distribute this electric load to Africa North and Africa South within the Comparative Reference case, we allocated the total Africa electricity demand by population in each projection year based on historical relationships. We also adjusted delivered fossil fuel prices from the WEPS+ supply modules to Africa. We distinguished the two regions by raising coal prices for Africa North to be similar to coal prices in Europe and the Middle East and by raising natural gas prices for Africa South because of more limited supply potential.[24] We assigned all generating capacity to either Africa North or Africa South based on country as reported in the Platts database.[25]

The greater WEPS framework maintains the 16 region structure, with Africa reported as 1 region. IEMM aggregates Africa North and Africa South into a single region before interfacing with the other WEPS modules.

Grid development cases

For previous *International Energy Outlook*s, we assumed that all electricity demand was met by power plants connected to the central electric grid, discounting what had traditionally been the less significant role played by off-grid power sources. The Maximum Grid Expansion case carries this assumption forward, assuming that the central grid continues to meet all electricity demand growth in Africa South.

[23] WEPS demand models estimate electricity consumption based on relationships between energy demand and economic activity. These estimations include on- and off-grid consumption to the extent that it is captured in EIA's *International Energy Statistics* database.

[24] Fuel prices (2010$ per million British thermal units)

	Coal—2030	Coal—2050	Natural gas—2030	Natural gas—2050
Reference case	6.26	7.33	7.64	21.20
TRC (Africa North)	6.41	7.81	7.64	19.20
TRC (Africa South)	6.26	7.33	8.64	22.94

[25] Platts World Electric Power Plant Database, June 2018 release

The Maximum Off-Grid case assumes that all incremental growth beyond the level in the Comparative Reference case in Africa South (as discussed below) is met by off-grid sources, specifically solar mini-grids and stand-alone photovoltaics. These cases illustrate opposite extreme possibilities for central grid expansion and off-grid development and so highlight the maximum potential change to Africa South's fuel mix. In both grid development cases, the input assumptions for Africa North are unchanged.

In the grid development cases, we bound the cases by assuming that Africa South reaches full electricity access by 2030 to serve as an upper estimate for the impacts of capacity expansion in Africa. We estimate the incremental demand arising from full electricity access separately by demand sector, as follows:

- Residential sector demand is based on reported electricity access for rural versus urban residents (from World Bank Survey data) as well as expected electricity consumption levels for rural and urban households (International Energy Agency estimates for rural and urban energy use). Assuming 100% urban and rural electricity access by 2030, we estimated that residential demand in Africa South would consume an extra 120 terawatthours (TWh) of electricity more than the Comparative Reference case by 2030 (with 107 TWh from rural and 13 TWh from urban populations). By 2050, the incremental demand associated with full electrification rises to 174 TWh, and it is attributable completely to the rural population electrification.
- For the commercial and industrial sectors, we estimated the incremental demand required to achieve full access as the replacement of lost load for commercial and industrial customers load attributed to Africa's less reliable power supply and delivery systems. The World Bank Enterprise Survey data for sub-Saharan Africa report that 51% of surveyed manufacturers, retailers, and service industries use self-generation (most use costly diesel generators) to meet 27% of their electricity demand because of the frequency and duration of electricity outages.[26] Based on this assessment, backup generation provided nearly 14% of electricity use in the commercial and industrial sectors. Under full access assumptions, the total commercial and industrial demand would increase to more than in the Comparative Reference case by 52 TWh in 2030 and 87 TWh by 2050—which is 14% higher than the Comparative Reference case's projected 2050 value of 628 TWh for Africa South.

Because IEMM models only central grid production, we adjusted the electricity demand modeled within IEMM to add incremental demand to account for full access in the Maximum Grid Expansion case. In the Maximum Off-Grid case, we assumed the incremental demand is met by off-grid supply, either with solar photovoltaic systems in mini-grid or stand-alone configurations.

Improving electricity infrastructure, and thereby increasing the reliability and reach of electric power in Africa, would almost certainly increase economic growth.[27] Presumably, the assumed additional electricity use in the two grid development cases would also result in additional macroeconomic effects that would affect the energy system as well, but we do not model that feedback loop in this analysis. Incorporating the macroeconomic effects of full electrification in Africa could change these results. As an example, universal electricity access could enable new kinds of labor, potentially raise personal income,

[26] Enterprise Surveys. World Bank.

[27] U.S.-Africa Energy Cooperation Initiative. U.S. Department of Energy.

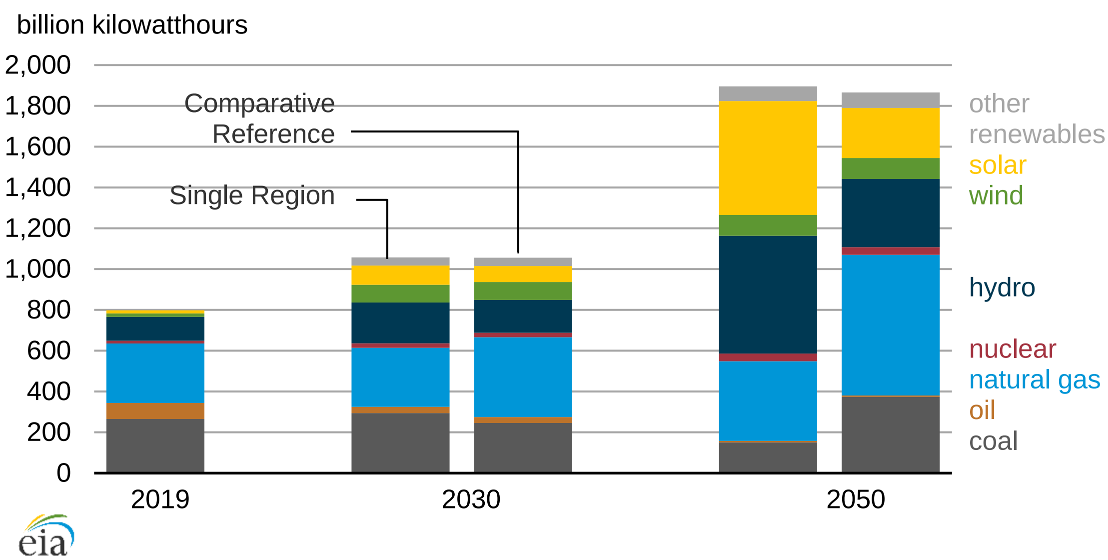
and lead to different patterns of electrical equipment usage. These kinds of analyses are beyond the scope of this paper.

Analysis

Regionality cases

In the Single Region case, with a single region treatment of Africa, generation from hydroelectric power is expanded, nearly quintupling from 117 TWh in 2019 to 577 TWh in 2050. With the significant hydroelectric resources available in Africa South, in a single region representation of Africa, hydroelectric power becomes the least-cost source. Hydroelectric power can serve demand growth across the continent, and the single region construction ignores transmission constraints that would make such an increase implausible (Figure 2).

Figure 2. Africa electricity generation by fuel source in regionality cases, 2019, 2030, and 2050[28]



In the Comparative Reference case, we modeled Africa North and Africa South as two separate regions. In this case, the role of hydroelectric generation in the electricity mix of Africa is tempered by allowing hydro growth only in the Africa South region, where most of the resource potential is located. Hydroelectric generation still expands, but at a lower rate, nearly tripling from 112 TWh in 2019 to 334 TWh by 2050, (Figure 2.) As the principal fuel for electricity generation in Africa South, coal-fired generation also increases in the Comparative Reference case proportionally with demand; this increase is more consistent with planned additions for the region.

In this case, we modeled natural gas to meet increasing electricity demand in Africa North, where natural gas is a prevalent resource, resulting in more steady growth in natural gas consumption than in the Single Region case. (Figure 3, Figure 4).

[28] End-use electricity demand in Africa differs in 2050 by 1.9% in 2050 between the two WEPS runs based on the different equilibrium between energy supply and demand reached in WEPS based on feedback from all models.

Figure 3. Share of electricity generation by fuel source in Single Region and Comparative Reference cases, 2019, 2030, and 2050

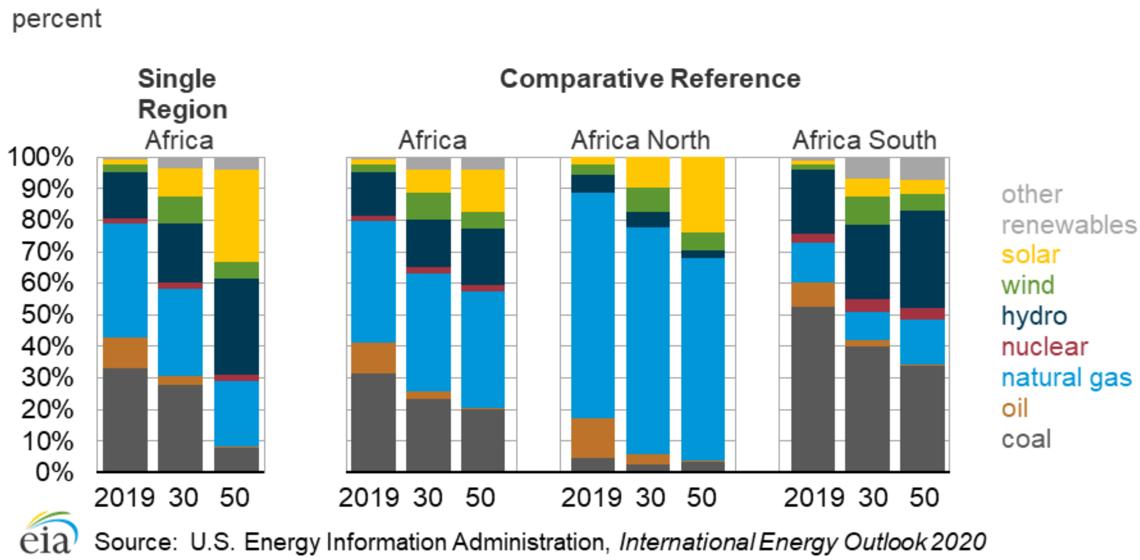
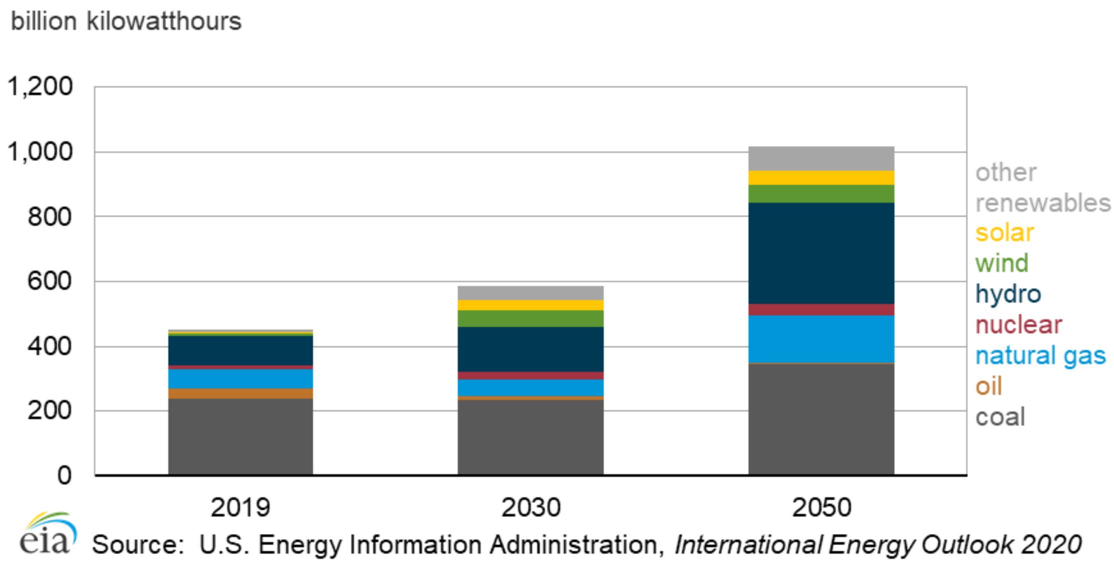


Figure 4. Africa South electricity generation by fuel source in the Comparative Reference case, 2019, 2030, and 2050



Grid development cases

Maximum Grid Expansion case

In the Maximum Grid Expansion case, we project the incremental demand between the Comparative Reference case and full access to electricity by 2030 in Africa South will be met by significant increases in fossil-fueled generation consistent with the primary source of baseload supply in the Comparative Reference case capacity mix. Natural gas-fired generation more than doubles by 2030 compared with the Comparative Reference case levels, and at the same time, coal-fired generation increases by 28%. By contrast, we project that solar and wind generation in the Maximum Grid Expansion case will remain nearly unchanged compared with Comparative Reference case levels by 2030. The ability of coal, hydro, and natural gas to provide baseload generation makes these technologies the least-cost options to meet demand by 2030, as opposed to solar, which can only generate electricity during daylight hours[29] (Figure 5, Figure 6).

Figure 5. Change in Africa South generation by fuel source—Maximum Grid Expansion and Maximum Off-Grid Development cases compared with the Comparative Reference case

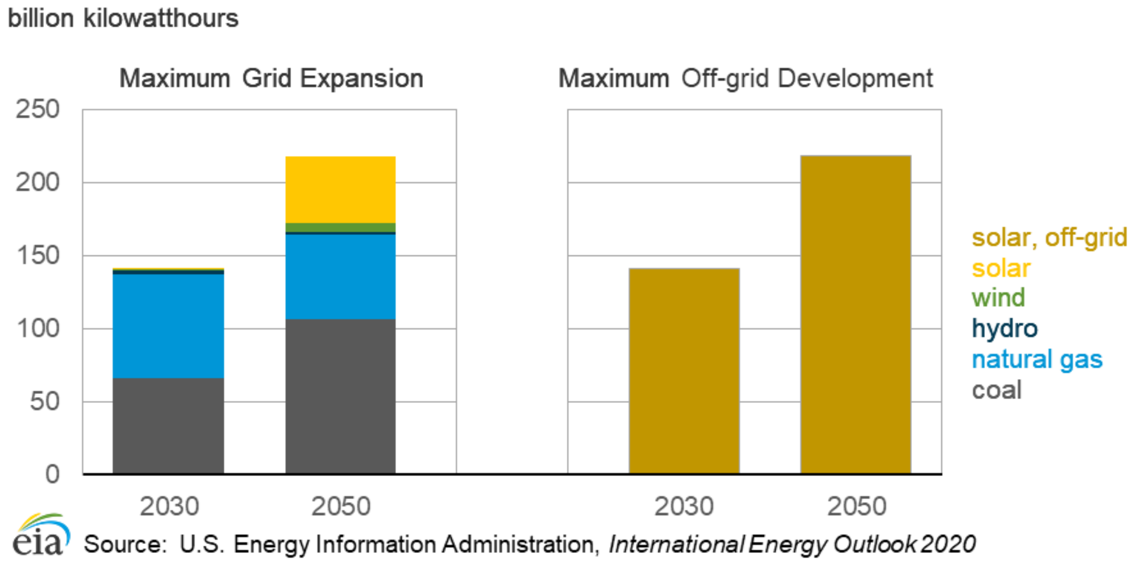
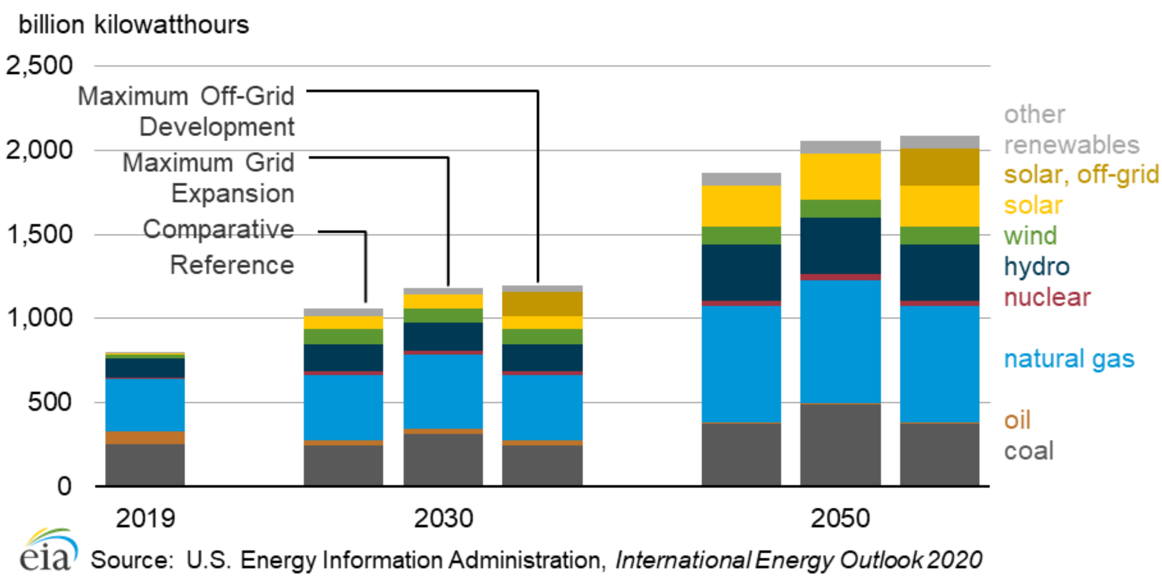


Figure 6. Generation in Africa (Africa North and Africa South) in three cases



[29] As modeled, energy storage may be used to arbitrage energy between broadly defined daytime and nighttime hours, helping to mitigate this limitation of solar.

In the Maximum Grid Expansion case for Africa South, coal generation nearly doubles from 237 TWh in 2019 to 457 TWh by 2050, compared with 345 TWh in the Comparative Reference case. Natural gas generation triples, from 57 TWh in 2019 to 193 TWh in 2050, compared with 143 TWh in the Comparative Reference case. Although the solar share of generation does not change significantly relative to its projected share in the Comparative Reference case, it still remains among the fastest growing of the three generating technologies in the Maximum Grid Expansion case. Between 2019 and 2050, solar generation increases from 6 TWh to 78 TWh. Despite this growth, solar represents just 6% of the generation mix in Africa South by 2050, compared with coal at 38%, hydro at 26%, and natural gas at 16%.

Maximum Off-Grid case

In the Maximum Off-Grid case, we assume solar off-grid sources completely supply new demand resulting from full access to electricity by 2030 in Africa South as the lowest-cost off-grid source. Solar capacity is projected to increase from 3 gigawatts (GW) in 2019 to 113 GW by 2050, compared with 20 GW by 2050 in the Comparative Reference case. These results shift the region's capacity expansion outlook. Solar becomes the dominant source of electricity supply in Africa South by 2050, accounting for 35% of the capacity mix, compared with a 22% share for hydro, 17% for coal, and 14% for natural gas.

The extent of the shift is reinforced from the change in generation in the Maximum Off-Grid case (Figure 6). Solar generation grows from 6 TWh in 2019 to 244 TWh by 2050. Coal and natural gas generation remain at levels projected in the Comparative Reference case. Coal grows by 1.2% per year to reach 345 TWh by 2050, and natural gas grows by 3% to end at 143 TWh. Solar holds 20% of the generation mix by 2050, contrasted with coal at 28%, hydro at 26%, and natural gas at 12%.

These two cases reflect bounding scenarios, depending on the connection option selected. Expansion of centralized grid service largely reinforces the existing sources of baseload supply. At the other extreme, assignment of the entire incremental demand to off-grid solar resources significantly alters the electricity supply in Africa South.

Conclusions

This paper discusses two related but separate topics: improvements to Africa's representation within EIA's modeling framework (WEPS) and the potential effects of off-grid development on fuel consumed by the electricity sector in Africa.

Within WEPS, reflecting the limitations of the existing transmission network imposed by adding regionality as a factor, results in a significantly altered outlook for expanding Africa's electric sector that reinforces its current reliance on fuels produced in each region. Compared with the IEO2019 analysis, coal has a greater role in Africa's generation mix, and the opportunity for hydroelectric generation is more limited. We will consider the two-region structure for future IEO Reference cases.

With regard to off-grid generation in Africa, although off-grid resources have a role to play in expanding electric service, based on the extent of the existing electric grid infrastructure in Africa North, the continent is unlikely to fully bypass centralized grid service. The cost competitiveness of grid connection at higher levels of electricity demand, as well as the extent of electrification in urban areas, is the primary factor in this conclusion.

The prospects for future development of the electric grid in Africa are uncertain, which is why this analysis focuses on bounding cases, rather than projecting the future adoption of either grid or off-grid approaches. At higher levels of off-grid access, the off-grid electricity consumption could significantly affect the electricity fuel mix of the continent by increasing the supply of electricity from renewables. Many futures remain possible. As an example, the Eastern Africa power pool was established in 2005, less than 20 years ago, which is a relatively short time in the context of large-scale infrastructure.

In addition, gaps remain in our understanding of the relationships between the critical behavioral variables related to electrification, both from a demand and supply perspective. Our ability to model electrification was limited by insufficient consumer behavioral data and uncertainty about how each sector of the economy may increase output and impose demands for electricity based on current levels of access to the grid. In particular, uncertainty about the changing rates of urbanization in African countries and the differences in potential energy demand, which require limiting assumptions for each demand profile and their likely development over time, is a factor.

To improve EIA's understanding of Africa's energy mix, EIA is monitoring leading indicators on electrification: government policy and investment from non-governmental organizations (NGOs) and private finance in the power sector in Africa. Additional data on electricity access policies, power grid development programs, and investment trends for their impact on the choice between grid and off-grid technology choices will reduce uncertainty in EIA's analysis. As part of broader EIA programs, we will also continue to track markets and infrastructure related to power system fuels, including terminals to support liquefied natural gas or imported coal, as well as the potential impact of international agreements on environmental targets, all of which have the potential to alter the pattern of electrification in Africa.