NOTES DE L'IFRI

SEPTEMBER 2022

New Paradigm for Electrification in Sub-Saharan Africa

How Are Decentralized Hybrid Systems Changing the Game?

Subsaharan Africa Center

Hugo LE PICARD

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ISBN: 979-10-373-0632-6

How to quote this publication:

Hugo Le Picard, "New Paradigm for Electrification in Sub-Saharan Africa: How Are Decentralized Hybrid Systems Changing the Game?", *Notes de l'Ifri*, Ifri, September 2022.

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Abstract

After several decades of reforms, the situation in centralized power sectors has hardly changed. The sub-Saharan power sector remains underdeveloped, and power sectors are experiencing significant financial difficulties that have been further exacerbated first by the effects of the pandemic and then the war in Ukraine. The operating losses of all African power sectors exceeded $150 billion in 2020. In view of the region's population growth, centralized grids cannot fully meet their electricity needs, even in areas with access.

Consequently, individuals and businesses are motivated to become more independent from the centralized grid to meet their electricity consumption needs. Market mechanisms are at work to fill the gaps created by the weakness of the centralized grid. The market for decentralized systems is experiencing strong growth in the region and has enormous potential in light of the grid's weakness: in addition to 600 million sub-Saharans without access to electricity, there are 500 million with access but who are coping with an unreliable or expensive grid. On a continent-wide basis, this is an opportunity worth more than $350 billion by 2030.

The large-scale expansion of the market for decentralized systems in areas covered by the grid is significant for the development of the sector. In view of the significant increase in urban population and the increasing attractiveness of decentralized systems, it cannot be excluded that the existing, yet weak, centralized grid may become partly redundant. However, a power sector that develops around decentralized systems can also have advantages, if these new uses are designed and integrated into the development policies of power grids.

These systems can provide faster access to electricity than the centralized grid for people without access. Similarly, the high modularity of these systems allows consumers with existing access to electricity to climb the energy ladder, enabling them to access new electrical services depending on their budget and needs. The lower cost of decentralized, renewable systems can also reduce the cost of electricity for commercial and industrial consumers, promoting their economic competitiveness and the penetration of renewable technologies across the continent. Decentralized generation capacity can also increase grid resilience, making consumers less dependent on centralized infrastructure. Finally, in the longer term, if electricity is generated primarily where it is consumed, it does not need to transit through transmission lines. It would also prevent electricity losses along transmission lines, that are high in many countries in the region. It would also limit the need for substantial investment in grid infrastructure

which is difficult to raise private funds for and for which the International Energy Agency (IEA) estimates an average of $40 billion per year is needed in the coming years.

While the region's centralized power sectors are experiencing increasing difficulties due to Covid-19 and the war in Ukraine, decentralized systems will be called upon to play a key role in expanding access to electricity on the continent now more than ever. With the availability of capital dwindling in emerging countries, development finance institutions (DFI) could further support investment in the ecosystem of businesses trading in green decentralized solutions to facilitate access to clean electricity on the continent.

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Introduction

Although sub-Saharan Africa experienced growth rates of 3.5% per year on average between 2009 and 2019,[1] the economies of various countries in the region remain precarious. Economic growth is still a major challenge for Africa in order to lift the population out of endemic poverty which is rife in the region, exacerbated by Covid-19 and the Russian invasion of Ukraine. In the past two years, 40 million Africans have been pushed back into extreme poverty,[2] and the region has experienced its first period of recession in over 25 years.[3] The economic growth rate also often falls behind the population growth rate.

The region's development and economic recovery are severely hampered by weak and inefficient power sectors that limit electricity consumption and consequently economic activity. The sub-Saharan power sector is the least developed in the world in terms of its electrification rate, consumption, installed capacity, and reliability of power supply. Out of the 1 billion people in the world who do not have access to electricity, nearly 600 million are sub-Saharan.[4] Despite a gradual increase in access to electricity over the past decade, the Covid-19 crisis has reversed the electrification trend. Nowadays, an additional 4% of sub-Saharan people live without electricity compared to 2019.[5]

In 2018, installed capacity throughout sub-Saharan Africa (excluding South Africa) amounted to about 80 gigawatts (GW), or nearly half that of France (130 GW), even though the region has 18 times more inhabitants.[6] The consumption gap with industrialized countries is enormous. The average consumption per year and per capita in sub-Saharan Africa was around 170 kilowatt-hours (kWh) in 2020.[7] This is sufficient to power a fan and two light bulbs for just under four hours per day. In comparison, the average annual consumption of a sub-Saharan African is one-twelfth that of a European, and one-fourteenth that of a French person.[8]

1. "World Development Indicators", World Bank, 2022, available at: https://databank.worldbank.org.
2. "Covid-19 (Coronavirus) Response", World Bank, 2021, available at: www.worldbank.org.
3. "Africa Energy Outlook 2022", International Energy Agency, 2022, available at: https://iea.blob.core.windows.net.
4. "World Development Indicators", World Bank, *op. cit.*
5. "Africa Energy Outlook 2022", *op. cit.*
6. "Africa Energy Outlook 2019", International Energy Agency, 2019, available at: www.iea.org.
7. "Africa Energy Outlook 2022", *op. cit.*
8. "World Development Indicators", World Bank, *op. cit.*

With frequent service interruptions – more than 51 hours of power outages on average per month in the region – the unreliability of the electricity supply is a major constraint for economic activity. It disrupts businesses and forces them to shut down their production lines during power outages, resulting in lost revenue from unfulfilled production. These power outages also incur high additional costs for businesses, such as the cost of restarting production lines or replacing machines damaged by voltage drops or sudden shutdowns. For example, the average losses of sub-Saharan businesses across the region due to power outages amount to 8.5% of their annual turnover.[9]

Consequently, all governments of developing countries emphasize the key role that the power sector plays in economic activity[10] and have made its development a priority.[11]

Although the current centralized infrastructure is unable to meet the African population's electricity consumption demand, the unmet need for electricity will continue to grow in the coming decades. In addition to the needs created by economic growth, Africa is undergoing significant urbanization that goes hand in hand with high population growth. Africa's population will double by 2050 from 1.1 to 2.1 billion people,[12] and the proportion of the population in urban and rural areas will be reversed. In thirty years, 60% of the population will be urban and 40% rural.[13] In addition to electrification targets, the continent will need to prepare sub-Saharan Africa's centralized grids to cater for nearly 1.2 billion city dwellers by 2050 and provide them with reliable, affordable, and sustainable electricity. The IEA estimates that electricity demand in Africa will increase by 75% by 2030.[14]

In light of these initial findings, several factors indicate that the sub-Saharan African power sectors are not pursuing the same development path, as that taken by industrialized countries during their growth that focused on the expansion of the centralized grid. Due to technological innovations and the lower cost of photovoltaic (PV) technology, decentralized technologies sold by private companies have become an attractive alternative to the national grid to electrify sub-Saharan populations and meet their power needs. Indeed, these technologies have the advantage of being relatively inexpensive compared to the expansion of

9. "World Development Indicators", World Bank, 2022, available at: https://databank.worldbank.org.

10. L. Parshall, D. Pillai, S. Mohan, A. Sanoh and V. Modi, "National Electricity Planning in Settings with Low Pre-Existing Grid Coverage: Development of a Spatial Model and Case Study of Kenya", *Energy Policy*, 2009.

11. "Africa Progress Report 2015 – Power, People, Planet: Seizing Africa's Energy and Climate Opportunities", Africa Progress Panel, 2015.

12. "World Population Prospects 2019", UN, 2019, available at: https://population.un.org.

13. "World Urbanization Prospects 2018", UN, 2018, available at: https://population.un.org.

14. "Africa Energy Outlook 2022", *op. cit.*

the grid and are rapidly deployed in remote areas. But although these decentralized technologies can play a key role in providing initial access to electricity in off-grid areas, they can also be used by consumers already connected to the grid to deal with its failures.

In this context, the lack of electrical infrastructure is attractive to companies that trade in these systems and view sub-Saharan citizens, either rural or urban, connected or not connected to the grid, as potential clients. In summary, sub-Saharan Africa is dealing with three concomitant trends shaping the expansion of power grids: the growing appeal of decentralized technologies, the low level of development of centralized grids, and population growth.

This paper analyzes the dynamics at work in the sub-Saharan power sectors and the effects of the deployment of decentralized technologies on the organization of centralized grids in sub-Saharan Africa. It will determine whether the new hybrid forms of expanding access to electricity are likely to be game changers for electrification, speeding up its deployment and improving the quality of supply, and ultimately, people's well-being and economic development.

In the first part of this paper, the structure, financial situation, and operational effectiveness of the region's centralized power sectors are studied to assess the current challenges and to better understand future ones. The second part shows the emergence of new market segments for decentralized systems in areas covered by the grid. The third part is dedicated to a foresight exercise to determine the consequences of deploying decentralized systems in grid-accessible areas to expand electrification in the region.

A Challenging Structure for Centralized Grids

Unfinished reform processes

Since the 1990s, reforms have been implemented in sub-Saharan Africa to increase electrification rates and rectify the chronic undercapacity of grid infrastructure and the sector's underperformance. But thirty years later, these reform processes have not been completed, and problems with accessing reliable, competitive, and widespread electricity are far from being solved, while markets are often inefficient.

These reforms, inspired by the liberalization processes in industrialized countries, comprised a series of steps designed to encourage more competition among the vertically integrated power sectors.

The objective was to separate management of the sector into different companies, to sell power generation or distribution facilities to private companies, to guide legislation toward "standard models", and to set up independent regulators.[15]

In many sub-Saharan countries, the generation sub-sector was first opened to competition to begin broader liberalization while rectifying chronic shortages in generation capacity. It was also intended to encourage state-owned transmission and distribution companies to improve their finances and management, using the private sector as a benchmark. In most countries, the main action has focused on facilitating the entry of independent power providers (IPP) into the generation sub-sector. The priority has been to enter into long-term power purchase agreements with IPPs. These long-term contracts provided businesses with a legally enforceable agreement in an industry characterized by weak regulation.[16]

15. J. E. Besant-Jones, "Reforming Power Markets in Developing Countries: What Have We Learned?", World Bank, 2006; K. N. Gratwick and A. Eberhard, "Demise of the Standard Model for Power Sector Reform and the Emergence of Hybrid Power Markets", *Energy Policy*, 2008; I. Malgas and A. Eberhard, "Hybrid Power Markets in Africa: Generation Planning, Procurement and Contracting Challenges", *Energy Policy*, 2011.
16. "The World Bank's Role in the Electric Power Sector: Policies for Effective Institutional, Regulatory, and Financial Reform", World Bank, 1993; P. A. Cordukes, World Bank and K & M Engineering and Consulting Corporation, "USA, Submission and Evaluation of Proposals for Private Power Generation Projects in Developing Countries", *Discussion Paper Series*, World Bank, 1994; R. Meyer, A. Eberhard and K. Gratwick, "Uganda's Power Sector Reform: There and Back Again?", Energy for Sustainable Development, 2018.

These long-term contracts between state-owned utilities and IPPs made it possible to quickly add new operating capacity from the outset. With part of the problem solved, policymakers had less incentive to pursue liberalization reforms and set up independent regulators. Consequently, the IPPs found themselves in markets where the level of competition was low and state-owned enterprises (SOE) retained significant control. The result was a hybrid development of the region's partly private, partly state-owned power sectors.[17]

Weak centralized grids for an ever-growing population

Despite progress in the region, centralized power infrastructure is still underdeveloped and bears no relevance to the needs of Africa's growing population.

Installed capacity in sub-Saharan Africa has increased in recent decades but remains woefully insufficient, from 68 GW in 2005[18] to 94 GW in 2014[19] to about 130 GW in 2018 (80 GW without South Africa[20]). Only eight countries on the continent, including South Africa, have a generating capacity above 3 GW. About a dozen countries have an intermediate level of installed capacity: ranging from 1,256 MW for Uganda to 5,382 MW for Ghana.[21] These capacities are very low considering the sub-Saharan population of more than 1.1 billion inhabitants, which is still growing. On a per capita basis, the capacity is 0.12 kW respectively.[22] In comparison, South Africa has a capacity of 0.98 kW and France 1.9 kW – or nearly 16 times more.

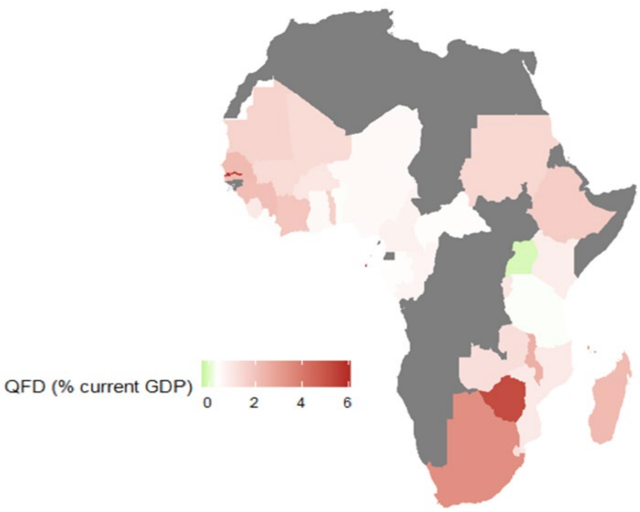
Also, this capacity is not always operational due to maintenance problems. Eberhard *et al.*[23] report that less than 75% of this capacity was fully operational continent-wide. Nigeria is a striking example: out of 12 GW installed capacity, only about 8 GW was actually operational, and about 4.1 GW was usable in 2018. Several factors may explain this situation, such as infrastructure maintenance issues, bottlenecks in power transmission capacity, gas supply problems at thermal plants, and water management issues for hydroelectric plants.[24]

17. I. Malgas and A. Eberhard, "Hybrid Power Markets in Africa: Generation Planning, Procurement and Contracting Challenges", *op. cit.*
18. A. Eberhard, O. Rosnes, M. Shkaratan and H. Vennemo, "Africa's Power Infrastructure", World Bank, 2011.
19. C. Trimble, M. Kojima, I. Perez Arroyo and F. Mohammadzadeh, "Financial Viability of Electricity Sectors in Sub-Saharan Africa: Quasi-Fiscal Deficits and Hidden Costs", *World Bank Policy Research Working Paper*, 2016.
20. "Africa Energy Outlook 2019", *op. cit.*
21. "UN Data: A World of Information", UN, 2021, available at: https://data.un.org.
22. "Africa Energy Outlook 2019", *op. cit.; "*World Development Indicators", World Bank, *op. cit.*
23. A. Eberhard, O. Rosnes, M. Shkaratan, and H. Vennemo, "Africa's Power Infrastructure", World Bank. *cit.*
24. W. Arowolo and Y. Perez, "Market Reform in the Nigeria Power Sector: A Review of the Issues and Potential Solutions", *Energy Policy*, 2020.

Similarly, grid infrastructure is also underdeveloped at the regional level. If you were to exclude the particular example of South Africa, sub-Saharan Africa has an average of 229 kilometers (km) of transmission lines per million inhabitants (pmh), as opposed to 800 km/pmh for France.[25] At the same time, the population density is two and a half times higher in France. There is no investment in transmission lines despite the considerable need. In 2018, only $10 billion was invested in grid infrastructure for all of Africa, while an estimated $60 billion was needed.[26] The IEA currently estimates that investment needs in grid infrastructure will be $40 billion on average per year for the 2026-2030 period.[27]

The weakness of power grids is explained by the poor financial reliability of almost all the power utilities in sub-Saharan Africa, which not only limits investments but also jeopardizes the survival of the existing power facilities. Most power utilities do not cover either their operating or fixed costs. Out of a review of 39 sub-Saharan African countries by the World Bank, 18 did not recoup their operating costs and experienced short-term financial difficulties.[28] Without an improvement in their finances, power utilities cannot afford to invest in expansion and the maintenance of existing infrastructure. In 2020, operating losses across all African power sectors were estimated to exceed US $150 billion.[29]

Figure 1: Power sector deficit as a percentage of GDP



Source: C. Trimble, M. Kojima, I. Perez Arroyo, and F. Mohammadzadeh, "Financial Viability of Electricity Sectors in Sub-Saharan Africa: Quasi-Fiscal Deficits and Hidden Costs", op. cit.

25. "Linking Up: Public-Private Partnerships in Power Transmission in Africa", *World Bank Publications – Reports*, World Bank, 2017.
26. "Africa Energy Outlook 2019", *op. cit*.
27. "Africa Energy Outlook 2022", *op. cit*.
28. C. Trimble, M. Kojima, I. Perez Arroyo, and F. Mohammadzadeh, "Financial Viability of Electricity Sectors in Sub-Saharan Africa: Quasi-Fiscal Deficits and Hidden Costs", *op. cit*.
29. "Africa Energy Outlook 2022", *op. cit*.

The pandemic has further compounded these financial difficulties. Power utilities in several countries have reported lower revenues due to reduced consumption by their industrial and commercial consumers because of an economic downturn. Furthermore, many countries have implemented emergency programs to tackle fuel poverty for residential consumers impoverished by the pandemic. Currently, the Ukrainian crisis and subsequent spike in oil prices are constraining the power sectors of countries dependent on oil for electricity generation.[30] Finally, the rise in U.S. interest rates, against a background of inflation, is draining available capital from emerging countries and increasing the cost of debt repayment. A vicious circle subsequently sets in, likely to reduce access to finance and make it more expensive.

In light of these structural and economic challenges, the region's centralized power grids are faced with an additional challenge: the significant population growth and urbanization in the region. The continent is now experiencing substantial population growth. According to UN projections, the sub-Saharan region's population will almost double in less than 30 years to reach 2.1 billion in 2050, compared to 1.1 billion today. Similarly, most of the population will be concentrated in cities, accounting for 58.1% of the population, or 1.2 billion inhabitants by mid-century.[31] In less than 30 years, the current equivalent of the entire sub-Saharan population will be concentrated in cities. In view of such an increase in urban population, the power sectors are finding it difficult to expand at the same rate, and the high concentration of African people in urban areas does not facilitate access to electricity. Despite many new connections made each year, electricity coverage of urban areas in sub-Saharan Africa is struggling to grow. Between 2019 and 2020, it even fell in certain countries.[32] This decrease in urban electricity coverage partly reflects the utilities' difficulty in keeping up with the rapid increase in the number of city dwellers.[33]

Therefore, even if new projects are developed each year, given the significant challenges facing centralized grids, it is difficult to imagine that they will be able to meet sub-Saharan Africa's power needs by themselves, even in areas covered by the grid.

30. "Africa Energy Outlook 2022", *op. cit.*
31. "World Urbanization Prospects 2018", *op. cit.; "*World Population Prospects 2019", *op. cit.*
32. In the Democratic Republic of Congo (DRC), Equatorial Guinea, Eritrea, Uganda, Niger, and Rwanda.
33. Some megacities such as Lagos, Luanda, Kinshasa, Dar es Salaam, and Nairobi have seen their population double in 20 years. These cities will continue to grow and some of them will see their population almost double again in the next 15 years.

Increased consumer empowerment in areas covered by the grid

As the urban population increases and centralized grids struggle to meet demand, people and businesses are encouraged to use additional power generation methods to satisfy their energy needs. Many decentralized technologies, originally intended for rural areas, are now being used in grid-accessible areas.[34]

The booming backup and hybrid generator market for commercial and industrial consumers

Across the continent, businesses are investing in backup generators to cope with grid failures and use electricity when the grid is down. The proportion of businesses experiencing outages is higher in Africa than in other regions of the world. Currently, less than one-third of businesses have reliable access to electricity.[35] This weakness in sub-Saharan power grids has a considerable negative impact on economies, accounting for, on average (depending on the country) a cost ranging from 1 to 4% of national GDP.[36]

In sub-Saharan Africa, more than 53.5% of businesses have a generator. In certain countries, like the Republic of Congo or Angola, more than three-quarters of businesses have one. At least 17 African countries are estimated to have more aggregate backup generator capacity than installed capacity on their centralized grid. Across the continent, there is an estimated 123 GW of operational backup generator capacity, almost equivalent to the total installed capacity on the centralized grid in all of Africa.[37]

34. Jalin, "Off-grid Electricity in Sub-Saharan Africa: From Rural Experiments to Urban Hybridisations", HAL, 2019; H. Le Picard and M. Toulemont, "Booming Decentralized Solar Power in Africa's Cities. Satellite Imagery and Deep Learning Provide Cutting-Edge Data on Electrification", *Briefings de l'Ifri*, Ifri, January 18, 2022, available at: www.ifri.org.

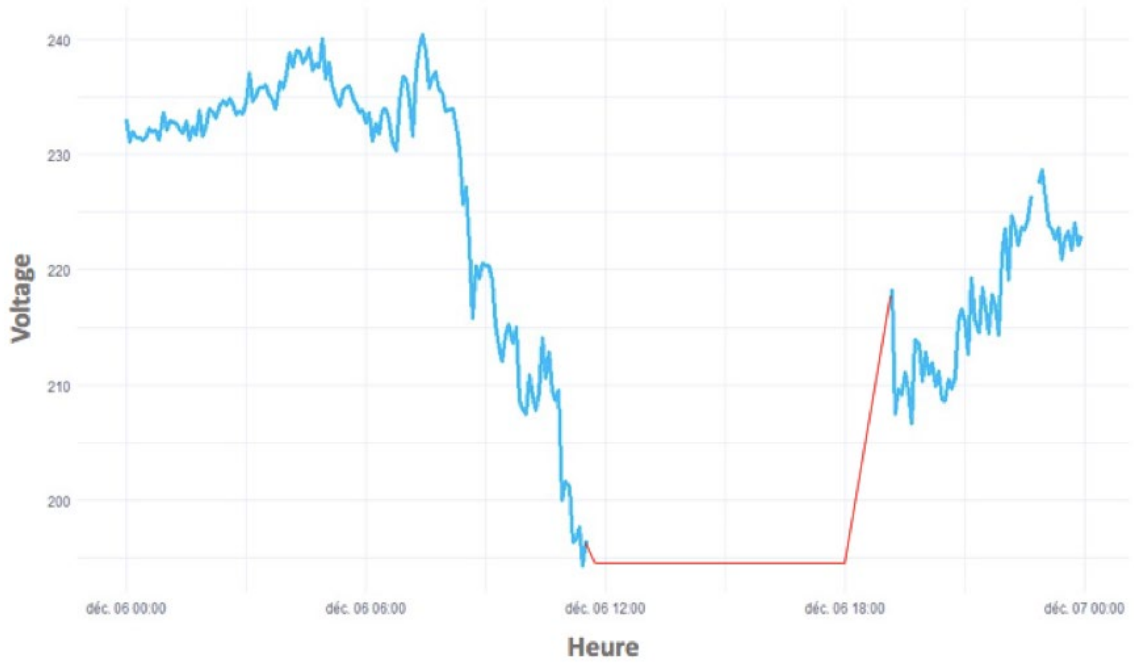
35. M. P. Blimpo, A. Postepska, and Yanbin Xu, "Why Is Household Electricity Uptake Low in Sub-Saharan Africa?", World Development, 2020.

36. V. Foster and C. Briceno-Garmendia, "Africa's Infrastructure: A Time for Transformation", World Bank, 2010.

37. B. Attia, "Utility 3.0: How Africa Is Remaking the Grid", Wood Mackenzie, 2022.

For example, in Nigeria, the poor reliability of the power grid and its inability to meet consumer demand has led to widespread use of backup generators in the country.[38] The country is a major market for these generators, particularly the large diesel generators that power businesses and industries, and small petrol generators used by small residential or commercial consumers.[39]

Figure 2: Voltage on the centralized grid during a typical day in Nigeria



Source: A2EI, Data release 2, 2019.

It is thought that Nigeria imports more than $250 million worth of generators and spare parts annually, making the country one of the largest markets for generators in the world and the largest in Africa.[40] The cumulative installed capacity of diesel generators in the country is estimated to be about 10–15 GW[41], or two to three times more than the capacity available on the centralized grid.

38. N. V. Emodi and K.-J. Boo, "Sustainable Energy Development in Nigeria: Current Status and Policy Options", *Renewable and Sustainable Energy Reviews*, 2015; N. Edomah, "Governing Sustainable Industrial Energy Use: Energy Transitions in Nigeria's Manufacturing Sector", *Journal of Cleaner Production*, 2019; A. Babajide and M. Centeno Brito, "Solar PV Systems to Eliminate or Reduce the Use of Diesel Generators at No Additional Cost: A Case Study of Lagos, Nigeria", Renewable Energy, 2021.
39. "The Dirty Footprint of the Broken Grid: The Impacts of Fossil Fuel Back-up Generators in Developing Countries", International Finance Corporation, 2019.
40. A. Babajide and M. Centeno Brito, "Solar PV Systems to Eliminate or Reduce the Use of Diesel Generators at No Additional Cost: A Case Study of Lagos, Nigeria", *op. cit.*
41. E. Arik, "Le marché des groupes électrogènes dans les Suds", *Research Report*, 2019.

As a result, more than 70.7% of businesses have or share a generator, almost 20% more than the average in the region (53.5%).[42] One million Nigerian households are reported to rely on their generators as their sole source of electricity and are completely emancipated from the centralized grid.[43] This extensive use of generators in the country means that Nigerian power generation is heavily dependent on oil. Therefore, the actual Nigerian electricity mix[44] is much more carbon-intensive than indicated. In fact, 40% of the electricity consumed in the country is generated by these oil-fired systems.[45]

However, the cost of electricity supplied by diesel generators can be three times higher than that of grid electricity.[46] The maintenance and operating costs of generators also represent a burden for businesses and an obstacle to their growth.[47] The cost to businesses of operating these generators is estimated to be $17 billion per year.[48] However, even though the use of these generators is expensive, these costs are low compared to the losses avoided by being able to generate power during centralized grid power outages.[49] In addition to the economic costs, pollution produced by diesel generators is substantial and presents a risk both for users' health and the environment.[50]

Sustained by the booming solar and storage battery markets, new innovative solutions for autonomous electricity generation are being developed, such as hybrid generators. These solutions combine a diesel generator, solar panels, and a storage system, ranging from small installations to small plants up to 2 MW.[51] This market is now gaining ground in Africa, particularly with manufacturers who want to safeguard themselves against grid unreliability while limiting their fuel consumption and financial exposure to volatile oil prices. With the increasing cost competitiveness of renewable energy, particularly solar energy, large commercial consumers are turning to hybrid systems to meet their electricity needs. These systems can provide electricity that is 23–60% cheaper

42. "World Bank Enterprise Surveys", World Bank, 2022, available at: www.enterprisesurveys.org.
43. "LSMS – Integrated Surveys on Agriculture: General Household Survey Panel 2010/11", vol. 2012, National Bureau of Statistics (NBS), 2012; M. O. Oseni, "Get Rid of It: To What Extent Might Improved Reliability Reduce Self-Generation in Nigeria?", Energy Policy, 2016.
44. The centralized electricity mix in Nigeria in 2019 was 21.4% hydroelectricity and 78.5% gas.
45. "Africa Energy Outlook 2022", *op. cit.*
46. D. Farquharson, P. Jaramillo, and C. Samaras, "Sustainability Implications of Electricity Outages in Sub-Saharan Africa", Nature Sustainability, 2018.
47. A. Aremu Adesanya and C. Schelly, "Solar PV-diesel Hybrid Systems for the Nigerian Private Sector: An Impact Assessment", Energy Policy, 2019.
48. "The Dirty Footprint of the Broken Grid: The Impacts of Fossil Fuel Back-up Generators in Developing Countries", International Finance Corporation, 2019.
49. M. O. Oseni and M. G. Pollitt, "The Economic Costs of Unsupplied Electricity: Evidence from Backup Generation among African Firms", *Cambridge Working Papers in Economics*, 2013; D. Farquharson, P. Jaramillo, and C. Samaras, "Sustainability Implications of Electricity Outages in Sub-Saharan Africa", *op. cit.*
50. "Diesel Power Generation: Inventories and Black Carbon Emissions in Nigeria", World Bank, 2014.
51. H. Le Picard, " [The Potential of Digital Technologies for Centralized Electricity Systems in Sub-Saharan Africa", *Notes de l'Ifri*, Ifri, October 2020, available at: www.ifri.org.

than using conventional generators, depending on the region.[52] Therefore, they help to improve supply reliability, reduce costs, and decarbonize business operations. Although still in its early stages, this market is growing rapidly. Its development is supported by various factors summarized in Table 1. Recently, one of the leading companies in the West African market raised over $38 million in January 2021 to expand and received direct financial support from Proparco and the European Union.[53]

Table 1: Innovation factors for the hybrid system market

Business model innovation	Transition in many sectors to outsourced utilities, allowing businesses to take advantage of renewable and decentralized energy systems without the initial capital requirements.
System price innovation	Significant cost reductions in renewable energy systems, particularly in the case of battery/storage systems.
Energy storage innovation	A promising development in alternative storage technologies that can store more energy at lower costs, e.g., dual solar and hydrogen storage systems.
Innovation in hybrid systems	Significant advances in combining various renewable energy sources, e.g., solar and gas/biogas, solar and hydrogen, solar and diesel generator.
Digital innovations	The rapid digitalization of decentralized systems now provides users with the ability to monitor, manage and troubleshoot systems remotely.

Source: V. Ezenwoko, "Daystar Power Group: The Development of Healthy Cities In Sub-Saharan Africa – Stepping Up Clean Electricity Uses", 2021.[54]

52. "Africa Energy Outlook 2022", *op. cit.*
53. "Daystar Power réalise une levée de fonds de 38 millions de dollars", Proparco, 2021, available at: www.proparco.fr.
54. V. Ezenwoko, "Daystar Power Group: The Development of Healthy Cities In Sub-Saharan Africa – Stepping Up Clean Electricity Uses", Presentation at "The Development of Healthy Cities in Sub-Saharan Africa: Stepping Up Clean Electricity Uses", Webinar organized in partnership between Columbia - Global Centers Nairobi, SIPA Center on Global Energy Policy (CGEP) and Ifri's Center for Energy & Climate, 2021.

Significant growth in the decentralized solar energy system market

The decentralized solar energy system market has experienced significant growth over the past decade in sub-Saharan Africa, particularly among residential consumers, due to the emergence of new economic models, such as pay-as-you-go[55] (PAYG). The market was worth $1.75 billion globally in 2019 and is growing steadily. Between 2017 and 2019, revenue generated by the sector increased by more than 30% per year. With 3.8 million units sold in 2018,[56] the decentralized solar market has reportedly raised more than $2.3 billion in investment since 2010 in sub-Saharan Africa alone.[57] The market first began in the region in off-grid rural areas, which still account for the lion's share of the market today, with over 588 million potential clients.[58]

However, the future of this market in sub-Saharan Africa is not necessarily limited to off-grid areas. Indeed, Gogla (2020[59]) estimates that the number of potential clients for these systems, who are connected to the centralized grid, could be more than 153 million. This figure only accounts for clients coping with an unreliable grid. Le Picard and Toulemont[60] have demonstrated that there is also a market for decentralized systems in areas where the grid is reliable, such as big cities in Africa, where large-scale systems are being used by the wealthier sectors of the population in large sub-Saharan cities regardless of the quality of electricity supplied by the grid.

Indeed, in addition to the benefits of a reliable electricity supply, there are many economic benefits linked to using these systems. A house fitted with a decentralized solar energy system can be protected from fluctuations in fossil fuel prices linked to, for example, using a diesel generator, as well as from increased electricity prices. Wealthy households have an even greater financial incentive to invest in these systems, as they pay higher prices that are increasing because of the sector's financial difficulties. Electricity from the centralized grid can be very expensive: in some African

55. This system provides access to a solar kit under a leasing contract that allows a solar energy system to be used while gradually paying it off with mobile money. Information technology is used to remotely and automatically lock the solar energy system if the consumer does not pay. This encourages the consumer to make regular payments to pay off their solar energy system. Consumers are attracted by this flexibility because it allows them to deal with unexpected financial events by being able to make multiple small payments instead of paying the full initial cost of the system.

56. "2020 Off-Grid Solar Market Trends Report", *Report*, Gogla 2020.

57. B. Attia, "Utility 3.0: How Africa Is Remaking the Grid", Wood Mackenzie, 2022.

58. "2020 Off-Grid Solar Market Trends Report", *Report*, Gogla, 2020.

59. *Ibid.*

60. H. Le Picard and M. Toulemont, "Booming Decentralized Solar Power in Africa's Cities. Satellite Imagery and Deep Learning Provide Cutting-Edge Data on Electrification", *op. cit.*

countries, even subsidized tariffs for the poorest consumers exceeded average tariffs in OECD countries (adjusted for purchasing power parity (PPP)). For low-income, off-grid consumers, smaller systems can be more attractive for meeting their electricity consumption needs because of the long waiting time and high grid connection cost. For example, grid connection costs are about $196 in Mali, $187 in Lesotho, and $287 in Benin,[61] while a medium-sized system (11–50 Wp) costs between $85 and $495.[62] Decentralized systems may also be available with easy-to-purchase schemes, such as PAYG, that further limit the initial costs for the consumer.

Another advantage of these decentralized solar technologies lies in their ability to be modulated and closely tailored to the consumers' electrical needs in terms of cost and consumption. Indeed, these decentralized solar energy systems are available in different product categories in terms of capacity, ranging from 1 Wp to 7,000 Wp+. The smallest solar devices (1–20 Wp) range from lamps providing basic lighting to small systems for charging phones. Medium-scale systems (100 Wp) can provide enough electricity to run a fridge or television. Finally, large-scale systems (7,000 Wp) can run a household at electricity consumption levels almost equivalent to the standards of industrialized countries.

Therefore, decentralized systems provide residential consumers with an attractive alternative to the grid, as they are more closely tailored to their needs, and especially to their budgets, in contrast to a centralized grid that provides a single, expensive and unreliable supply. Thus, the decentralized system market in sub-Saharan Africa may not only be limited to 600 million sub-Saharans without access to electricity, but could also extend to the whole population, i.e., 1.1 billion potential clients today or 2.1 billion in 2050. The entire decentralized solar energy system market would be worth more than $350 billion continent-wide by 2030.[63]

61. M. Kojima, X. Zhou, J. Han, J. F. De Wit, *et al.*, "Who Uses Electricity in Sub-Saharan Africa? Findings from Household Surveys", *Policy Research Working Paper Series*, World Bank, 2016.
62. "2020 Off-Grid Solar Market Trends Report", Gogla*, op. cit.*
63. B. Attia, "Utility 3.0: How Africa Is Remaking the Grid", *op. cit.*

The potential effects of consumer empowerment on centralized grids

Given the challenges facing centralized power grids, increased penetration of decentralized systems in areas covered by the grid could have profound implications for the sector's development.

Toward a weakening of the sector's financial sustainability

This trend of consumer empowerment regarding the centralized grid has an impact on centralized power sectors. It is a trend that risks reducing revenue from electricity sales by increasing payment defaults or by diverting consumers from the centralized grid. This may worsen the already poor financial sustainability of utilities.

It is already difficult for utilities to collect revenue from electricity sales because of the significant challenges they face in obtaining payments for the electricity they bill. In more than ten African countries, non-payments account for more than 20% of the electricity billed.[64] With consumer empowerment, these problems are likely to worsen. Pueyo[65] argues, particularly in Ghana, that the wealthiest clients are turning away from the national grid and investing in self-generation with diesel generators or PV systems to cope with expensive and unreliable electricity from the centralized grid. According to the author, the Ghanaian regulatory bodies have even recommended reducing electricity prices to discourage consumers from turning away from the grid. Oseni[66] reports similar trends in Nigeria.

Similarly, Le Picard and Toulemont's[67] study analyzes several million satellite images, representing a total surface area of 4.6 billion square meters, in 14 sub-Saharan African capitals using Deep Learning tools to

64. C. Trimble, M. Kojima, I. Perez Arroyo, and F. Mohammadzadeh, "Financial Viability of Electricity Sectors in Sub-Saharan Africa: Quasi-Fiscal Deficits and Hidden Costs", *op. cit.*

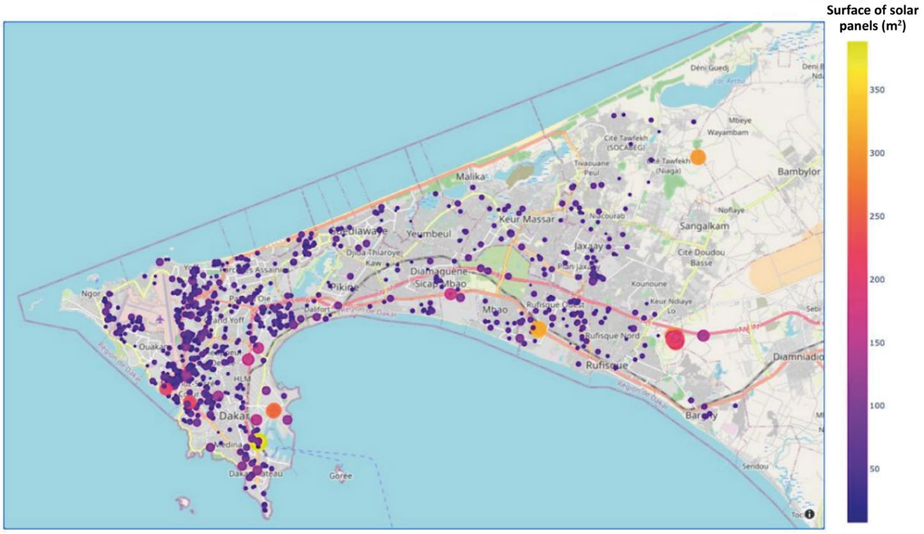
65. A. Pueyo, "What Constrains Renewable Energy Investment in Sub-Saharan Africa? À [A] Comparison of Kenya and Ghana", World Development, 2018.

66. M. O. Oseni, "Get Rid of It: To What Extent Might Improved Reliability Reduce Self-Generation in Nigeria?", *op. cit.*

67. H. Le Picard and M. Toulemont, "Booming Decentralized Solar Power in Africa's Cities. Satellite Imagery and Deep Learning Provide Cutting-Edge Data on Electrification", *op. cit.*

search for decentralized solar energy systems. In particular, they show that decentralized solar energy systems are adopted by the wealthier sectors of the population in large sub-Saharan cities, even in areas with reliable supply. The following map from the study shows the strong growth of decentralized solar energy systems in the city of Dakar.

Figure 3: Penetration of decentralized solar energy systems in the city of Dakar



Source: H. Le Picard and M. Toulemont, "Booming Decentralized Solar Power in Africa's Cities. Satellite Imagery and Deep Learning Provide Cutting-Edge Data on Electrification", op. cit.

Defection by the wealthiest grid clients to decentralized systems would be particularly problematic for the sector.[68] For example, in Kenya, the state-owned power utility earns more than 54% of its revenue from around 700 clients. Increased financial difficulties in the sectors could lead to lower investment in infrastructure maintenance and further price increases. In turn, this could help to make decentralized systems even more attractive and reinforce the trend toward consumer empowerment in the region.

A mixed effect on the development of renewable energy in the region

If the finances of national utilities are weakened by the defection of consumers from the grid, then there is a risk the deployment of centralized renewable energy will slow down in the region. For renewable projects to be funded on favorable terms, they require a guaranteed payment over the life of the facilities, i.e., for more than 25 years, as they have high capital expenditure (CAPEX) to operating costs and low operating costs (OPEX).

68. B. Attia, "Utility 3.0: How Africa Is Remaking the Grid", *op. cit.*

Such a time scale carries many risks, that are higher when national utilities are experiencing considerable financial difficulties.

Conversely, given the rapidly increasing energy demand and financial difficulties of the sub-Saharan power sectors, "backup" power plants are becoming increasingly attractive with low CAPEX but higher OPEX. These solutions take the form of generators in containers assembled to form power plants that can be installed in just a few weeks. They are powered by coal or fuel oil and are leased at great cost by specialist companies. These power plants can be installed without any guarantee from the national utilities and can be quickly withdrawn in the event of payment default.[69] However, these solutions are expensive: their electricity costs are two to three times higher than those of conventional power plants. These backup power plants are mainly powered by diesel or HFO, whose prices were reported to be around $0.30 and $0.40 per kWh during the 2014-2016 period.[70] Russia's invasion of Ukraine and the subsequent increase in oil prices also had an impact on the cost of these power plants.

These power plants tend to flourish in countries where the power sector's finances are in dire circumstances. Contrary to their initial objectives, they are often embedded in national power markets for the long term, either through lease renewals or through buyouts by state-owned enterprises.

Without improving the power sector's financial sustainability, it will be difficult to develop centralized, high CAPEX, low OPEX renewables. Today, despite its immense solar potential, Africa only has 1% of the world's installed PV capacity[71] or just half of the installed solar capacity of a country like the United Kingdom.[72]

In light of these challenges, developing the decentralized solar energy system market in rural and urban areas in sub-Saharan Africa is an alternative way to capitalize on the region's immense solar potential, and consequently, increase renewable capacity. In a sample of 14 sub-Saharan cities, decentralized solar energy systems accounted for nearly 10% of centralized solar capacity installed in the region, or between 180 and 230 MW.[73] The IEA estimates that growth in the decentralized solar energy system market will significantly outstrip the addition of new centralized solar capacity in Africa over the next decade.[74]

69. H. Le Picard, "The Potential of Digital Technologies for Centralized Electricity Systems in Sub-Saharan Africa", *op. cit.*
70. C. Trimble, M. Kojima, I. Perez Arroyo, and F. Mohammadzadeh, "Financial Viability of Electricity Sectors in Sub-Saharan Africa: Quasi-Fiscal Deficits and Hidden Costs", *op. cit.*
71. "Africa Energy Outlook 2022", 2022, *op. cit.*
72. A. Roussi, "Solar Power Shines Through after a Slow Start in Africa", *Financial Times*, 2022.
73. H. Le Picard and M. Toulemont, "Booming Decentralized Solar Power in Africa's Cities. Satellite Imagery and Deep Learning Provide Cutting-Edge Data on Electrification", *op. cit.*
74. "Africa Energy Outlook 2022", 2022, *op. cit.*

Consumer empowerment could consequently have a double effect on solar energy system expansion in the region. It could weaken utilities' finances and therefore limit the potential expansion of centralized solar energy systems while being a vector for increased decentralized solar capacity.

Conclusion

After several decades of reforms, the situation in centralized power sectors has hardly changed. The sub-Saharan power sector remains underdeveloped both in terms of electrification, consumption, and installed capacity. Furthermore, the power sectors are experiencing significant financial difficulties that have been further exacerbated first by the effects of the pandemic and then the war in Ukraine.

Given the significant challenges facing centralized grids and the region's increasing population and urban growth, centralized grids cannot fully meet the population's electricity needs, even in grid-accessible areas. Consequently, individuals and businesses are motivated to become more independent from the centralized grid to meet their electricity consumption needs.

Market mechanisms are at work to fill the gaps created by the weakness of the centralized grid: companies trading in decentralized power generation systems are taking advantage of this. The market for decentralized systems is experiencing strong growth in the region and has enormous potential in light of the grid's weakness: in addition to 600 million sub-Saharans without access to electricity, there are 500 million with access but coping with an unreliable or expensive grid. The actual market for these systems is estimated to be 1.1 billion potential clients today or 2.1 billion in thirty years. On a continent-wide basis, this is an opportunity worth several hundred billion dollars per year by 2030.

The trend of early decentralization of services under pressure from demand and a proactive private sector is not new in sub-Saharan Africa. It is worth recalling that with the advent of the mobile in the mid-1990s, Africa "leaped" forward, from the challenging expansion of national fixed networks to mobile telephony.

The large-scale expansion of the decentralized systems market in areas covered by the grid is significant for development in the sector. Given the significant increase in urban population and the increasing attractiveness of decentralized systems, it cannot be excluded that the existing, yet weak, centralized grid may become partly redundant.

However, a power sector that develops around decentralized systems can also have beneficial effects if these new uses are designed and integrated into the development policies of power grids. These systems can provide faster access to electricity than the centralized grid for people without it. Similarly, the high modularity of these systems allows consumers with existing access to electricity to climb the energy ladder, enabling them to access new electrical services depending on their budget and needs.

The lower cost of decentralized, renewable systems can also reduce the cost of electricity for commercial and industrial consumers, promoting their economic competitiveness and the penetration of renewable technologies on the continent. Diesel generators could thus be replaced by decentralized solar energy systems, increasing the total solar capacity. To date, Africa accounts for only 1% of the world's installed centralized solar capacity, although it is home to 60% of global solar resources.[75] Backup generators are estimated to account for 127 GW of capacity on the continent, 13 times more than the centralized PV capacity currently installed there.[76]

Decentralized generation capacity could also increase grid resilience to events that could damage them, making consumers less dependent on centralized infrastructure. For example, last January Kenya suffered a nationwide power outage after the collapse of transmission towers. This directly affected residential and commercial consumers, as well as critical infrastructure such as hospitals for over 24 hours. Consumers using decentralized systems, however, continued to receive electricity during this period.[77]

Finally, in the longer term, if electricity is generated primarily where it is consumed, it does not need to transit through transmission lines. This should also prevent losses during transmission that are high in many countries in the region: 24 countries have losses that are above 20% and are sometimes more than 48%.[78] This would also limit the need for enormous investments in grid infrastructure, which is difficult to raise private funds for and for which the IEA estimates an average of $40 billion per year is needed in the coming years.[79]

In view of these developments, we may ask whether in the future the sub-Saharan electricity market will continue to be built around central infrastructure managed by the public sector, or whether the vibrant entrepreneurial ecosystem that is currently exploding in Africa in the tech, e-commerce, and mobile finance sectors will have largely taken over the shortfalls in public services in the power sector too. While the region's centralized power sectors are experiencing increasing difficulties due to Covid-19 and the war in Ukraine, decentralized systems will be called upon more than ever to play a key role in expanding access to electricity on the continent. With the availability of capital dwindling in emerging countries, DFIs could further support investment in the ecosystem of businesses that trade in green decentralized solutions to facilitate access to clean electricity on the continent.

75. "Africa Energy Outlook 2022", 2022, *op. cit.*
76. B. Attia, "Utility 3.0: How Africa Is Remaking the Grid", *op. cit.*; "Renewable Capacity Statistics", IRENA, 2021, available at: www.irena.org.
77. A. Roussi, "Solar Power Shines Through after a Slow Start in Africa", *op. cit.*
78. C. Trimble, M. Kojima, I. Perez Arroyo, and F. Mohammadzadeh, "Financial Viability of Electricity Sectors in Sub-Saharan Africa: Quasi-Fiscal Deficits and Hidden Costs", *op. cit.*
79. "Africa Energy Outlook 2022", *op. cit.*

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