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Interconnected Mini-Grids Have a Big Role to Play in Building High-Energy, Low-Carbon Futures

High-level takeaways from Joel Yongoua Nana and Michael O. Dioha, "On the role of interconnected mini-grids in net-zero emissions electricity system: insights from Nigeria," *Environmental Research Letters* 19 (2024) [1]

Summary: As developing countries aim to expand electricity access, increase consumption, and reduce carbon emissions, a significant transformation of the power sector is essential. Mini-grids have long been deployed in remote, off-grid locations. But interconnected mini-grids (IMGs), which generally combine solar PV with battery storage and are interconnected to the main grid, have more recently emerged as a promising solution in markets with power quality and reliability challenges. What role could IMGs play in helping countries achieve high-energy, low-carbon futures? Using Nigeria as a case study, we find that IMGs offer the potential to deliver clean, reliable, and affordable energy to millions of people underserved by grid connections. While IMGs contribute to modest cost reductions, they could play an important role in achieving carbon neutrality, particularly in the context of Nigeria's high-energy future.

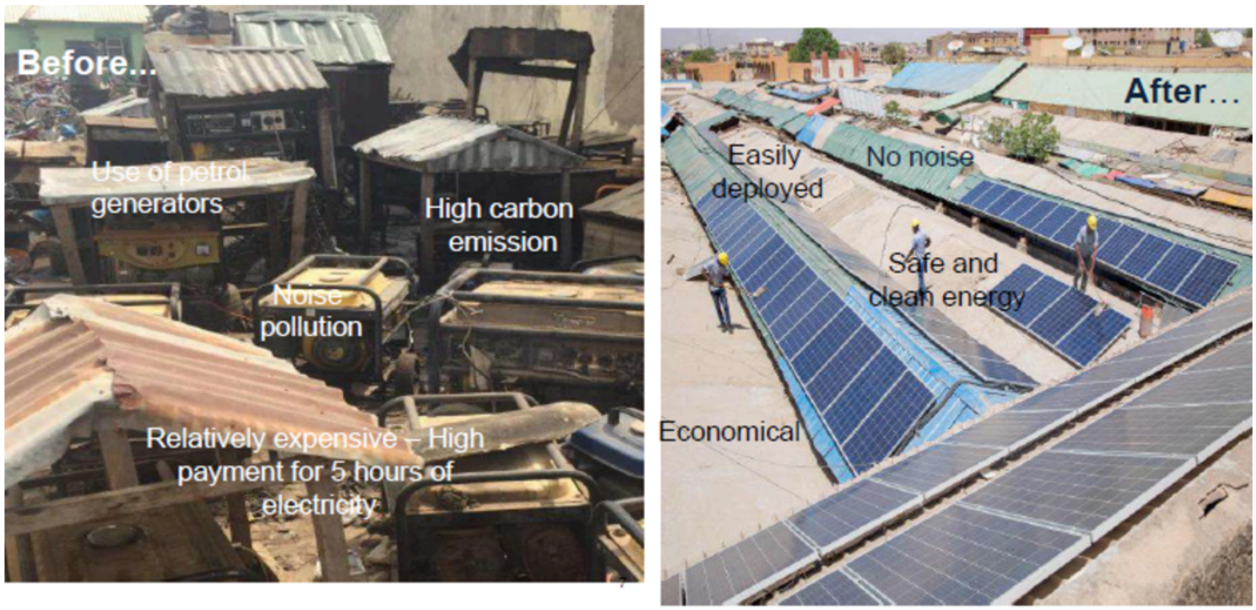
Why it matters: On April 15, 2024, Nigeria experienced its fifth power grid collapse of the year, with generation capacity plummeting from 4,020 MW the previous day to approximately 50 MW [2]. The incident occurred just two weeks after the regulatory authority implemented a 230% increase in electricity tariffs targeting higher-income consumers. This failure is part of a troubling pattern, with the grid collapsing 46 times between 2017 and 2023.

The epileptic nature of Nigeria's power supply has led the country to become Africa's largest market for backup diesel generators. The estimated installed capacity of Nigeria's 22 million small backup generators is an astonishing 42,000 MW — about eight times the installed peak generating capacity of the main grid [3]. Concurrently, Nigeria has seen a significant uptick in other kinds of decentralized power production in recent years, especially renewables-powered mini-grids, to support national electrification efforts and provide electricity access to the 35% of Nigerians who are currently unserved.

Until recently, all mini-grids in Nigeria were stand-alone installations built and operated for communities in remote off-grid locations. However, since 2018, the co-location and interconnection of mini-grids to the main grid, coined "interconnected mini-grids (IMG)", has become a viable solution to solving Nigeria's energy challenges. Development partners and the private sector, in collaboration with the Nigerian Rural Electrification Agency (REA), have innovatively deployed solar PV plus battery storage IMGs to improve power quality and reliability for millions of Nigerians receiving poor grid services.

And, in a major policy boost for IMGs, the Nigerian Electricity Regulatory Commission (NERC) recently published new rules that require electricity distribution companies (DisCos) to procure at least 10% of their contracted energy from distributed generation sources [4].

FIGURE 1: Mokoloki market interconnected mini-grid, Nigeria.



Source: Rensource

Our study

We set out to understand the potential influence of IMGs on energy transitions in emerging markets. Nigeria's complex electricity challenges, its commitment to achieving net-zero emissions by 2060, and the growing enthusiasm around IMGs make it a fascinating case study.

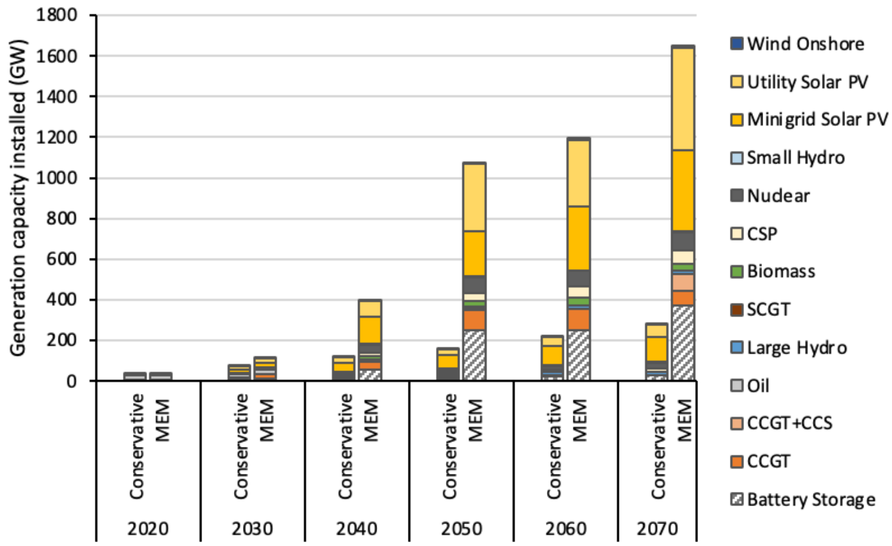
To investigate IMG's role in supporting Nigeria's energy transition, we used a capacity expansion energy system model to explore scenarios based on different assumptions about Nigeria's net zero target years and future electricity demand, under both conservative and ambitious projections. The conservative scenario uses the baseline future electricity demand projected in IRENA's Nigeria Renewable Energy Roadmap study [5]. In the ambitious scenario, the study modeled an electricity demand forecast to meet the Modern Energy Minimum (MEM) (1,000 kWh per capita annually) by 2030 and the median for high-income countries (6,720 kWh) by 2050 [6], reflecting Nigeria's aspirations for industrialization, employment, higher incomes, prosperity, and economic transformation. Within each scenario, we assessed the role of IMGs and other generating assets in Nigeria's pursuit of a net-zero electricity system by 2050 and 2070. We analyzed variations across the scenarios in electricity generation mix, carbon emissions, and total discounted cost of the energy system.

What we learned

The study provided several insights into the role of IMGs in Nigeria's energy transition:

1. **IMGs can play a key role in improving cost, reliability, and local air quality:**
    - IMGs provide a vital solution for enhancing access and grid reliability, with the potential to serve as a critical lifeline for the 78% of Nigerian grid customers who only receive electricity for half of the year.
    - Despite the significantly higher capacity addition to meet the MEM target, the total discounted system cost, accounting for the time value of money, is only twice that of investments relative to the conservative scenario. In fact, ESMAP [3] reports that Nigerian customers served by IMGs could pay about 65% less for energy services than when serviced by DisCos.
    - Across all modeled scenarios, IMGs facilitate the accelerated phasing out of expensive and noisy diesel backup generators, with the added co-benefits of decreasing local air pollution — a common issue in areas heavily reliant on these backup generators.
2. **IMGs can help achieve SDG7 and increase electricity consumption in line with the MEM:**
    - The study found that meeting the MEM in Nigeria in a net-zero setting necessitates a significant capacity expansion — approximately six times greater than currently projected in the Nigeria Renewable Energy Roadmap (figure 2). This grid expansion would require about 29 GW of new capacity annually (mostly solar), of which at least 10% could cost-effectively come from IMGs.
    - In general, the shift towards a MEM target in a deeply decarbonized system will require higher initial capital outlay and increased complexity in managing a more diverse energy system, challenging Nigeria's financial and infrastructural capabilities. However, successfully mobilizing these resources presents an important opportunity for job creation, local renewable energy business growth, and skill development, particularly as distributed generation typically supports more jobs per MW than conventional power sources.
3. **IMGs offer a cost-effective and flexible solution for achieving net-zero emissions:**
    - The study underscores that to achieve Nigeria's net-zero target by 2050, it will be necessary to decommission existing thermal generation assets early. Traditional energy models often fill this gap through the deployment of new thermal power plants equipped with carbon capture and storage (CCS) technologies. However, the findings indicate that IMGs, when coupled with battery storage, provide enough cost-effective firm capacity to substantially reduce the need for CCS technology while also curtailing the need for new thermal power investments that may otherwise become stranded assets.

FIGURE 2: Electricity generation capacity (GW) by technology under the conservative and MEM scenarios.



Note: The conservative scenario uses projected electricity demand from Nigeria's Renewable Energy Roadmap, while the ambitious MEM scenario forecasts a more ambitious electricity demand, aligning with Nigeria's development goals.

Policy Implications

While IMGs have great potential to accelerate Nigeria's energy transition, their success hinges on robust regulatory and policy support. Essential measures include:

- **Appropriate tariff setting.** Crucially, Nigerian utilities must address revenue loss, particularly when tariffs are not cost-reflective. Regulatory authorities should facilitate the sustainable co-location of IMGs to the main grid through sound tariff design that allows utilities to recover all operating and network costs (including use of system charge) and future grid upgrade costs as a result of IMG interconnection.
- **Licensing and concession processes.** The process for obtaining concessions or licenses to operate IMGs should be clearly regulated and include detailing necessary checks, responsibilities, obligations, and acceptable response times to streamline and standardize operations.
- **Interconnection standards.** Traditional distribution networks are not designed for generators at the end of feeders, particularly with IMGs injecting significant amounts of power upstream. Regulators should clearly define and communicate compliance standards for IMGs at the point of connection/interface with the main grid.
- **Data availability.** Authorities, in collaboration with utilities, should curate and regularly publish grid expansion data or data on the spatial distribution of areas where IMGs can deliver maximum value for distribution companies and grid-connected customers.

- **Metering and billing systems.** Financial transactions with IMG operators require specific metering specifications and billing system enhancements. Regulatory frameworks should specify new billing and metering requirements to facilitate these transactions.
- **Investments for grid updates.** Policymakers need to develop comprehensive roadmaps for grid modernization, clearly identifying investment priorities for distribution grid upgrades to facilitate IMG integration. These upgrades may include constructing and upgrading distribution lines, improving existing substations, and upgrading transformers. Additionally, in certain instances, DisCos will need to establish new medium-voltage distribution lines to connect IMGs to the grid.

The deployment of IMGs is a formidable example of transformational change sweeping the power sector, with the potential to dramatically alter African grids. While IMGs are not a panacea for all energy challenges facing emerging markets, they can play a crucial role in alleviating energy poverty by providing reliable power to underserved homes and businesses, contributing to local wealth creation through job opportunities and ownership of distributed generation assets, and reducing carbon emissions and local air pollution.

Endnotes

1. Nana, J.Y. and Dioha, M.O. (2024). "On the role of interconnected mini-grids in net-zero emissions electricity system: insights from Nigeria," Environmental Research Letters, 19(3), p. 034014. Available at: https://doi.org/10.1088/1748-9326/ad259f.
2. https://www.sabcnews.com/sabcnews/nigerias-grid-collapses-again/
3. https://www.esmap.org/Mini-Grid-Solutions-for-Underserved-Customers
4. https://businessday.ng/energy/article/nerc-mandates-discos-to-source-10-of-power-from-renewables/#:~:text=The%20Nigerian%20Electricity%20Regulatory%20Commission,%2C%20by%20April%201%2C%202025.
5. https://www.irena.org/Publications/2023/Jan/Renewable-Energy-Roadmap-Nigeria
6. Details about the MEM are available at: https://energyforgrowth.org/wp-content/uploads/2019/01/FULL-Modern-Energy-Minimum-final-Jan2021.pdf.