ENERGY MARKET AND REGULATORY CONSULTANTS

UNDER THE GRID

IMPROVING THE ECONOMICS AND RELIABILITY OF RURAL ELECTRICITY SERVICE WITH UNDERGRID MINIGRIDS

BY SACHIKO GRABER, PATRICIA MONG, AND JAMES SHERWOOD

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SUGGESTED CITATION

Graber, Sachiko, Patricia Mong, and James Sherwood. *Under the Grid: Improving the Economics and Reliability of Rural Electricity Service with Undergrid Minigrids.* Rocky Mountain Institute, November 2018. **www.rmi.org/insight/under-the-grid/**

ACKNOWLEDGMENTS

The authors thank the following individuals and organisations for offering their insights and perspectives on this work:

Chibuikem Agbaegbu, Power for All
Roseann Casey, USAID
Kendall Ernst, RMI
Edward LaFarge, USAID
Ify Malo, Power for All
Gregory Miller, Virgin Unite
Abimbola Odubiyi, Abuja Electric Distribution Company
Abdulmumini Yakubu, NiRER

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EXECUTIVE SUMMARY

Throughout sub-Saharan Africa, hundreds of millions of people live “under the grid.” Such communities are within distribution company (DisCo) territory, but receive unreliable, inconsistent, and/or low-quality power that does not meet their needs—or they receive no power at all. These communities are thus undergrid yet also underserved.

There are about as many undergrid customers as off-grid customers in the world, with roughly 200 million households in each category. They face many of the same electrification challenges, especially around accessing the development benefits of electricity. However, governments and development partners tend not to focus on undergrid customers because, in theory, they already have at least nominal electricity access.

There is a new opportunity to better serve these customers and their communities through minigrids that utilize existing distribution and incorporate distributed energy resources. We call these systems **undergrid minigrids.**

NIGERIA IS A PROMISING TESTING GROUND FOR UNDERGRID MINIGRID DEPLOYMENT

Nigerian utilities have the third-lowest reliability in sub-Saharan Africa, 90% of grid connections are considered unreliable, and outages are longer and more frequent in rural areas. Customers often average just two hours per day of unreliable, low-quality electricity service.

However, the Nigerian government has demonstrated a commitment to increase both electricity access and reliability in part through significant support for undergrid efforts via regulatory and policy leadership.

NIGERIAN DISTRIBUTION COMPANIES AND THE COMMUNITIES THEY SERVE BOTH FACE CHALLENGES

Low collection rates, unmetered customers, and other challenges mean that DisCos are largely unable to recover revenue for the electricity they provide in rural areas, while still shouldering many costs.

Thus today, revenue currently only covers approximately 35% of total DisCo costs, and in a typical rural community they lose an average of ₦72 (US$0.21) per kWh distributed. To break even at current collection rates (approximately 30%) and levels of service (approximately 2 hours per day) in rural communities, tariffs would need to be 10 times higher. This would obviously be untenable and unfair to these rural customers. Alternatively, DisCos would need perfect collection (100%) and perfect service (24 hours per day) to break even at today’s tariffs.

Meanwhile, underserved customers on the receiving end of unreliable, low-quality grid electricity must turn to expensive, polluting, noisy diesel and petrol generating sets that can cost ₦200 ($0.60) per kWh or more.

Ultimately, all stakeholders are challenged to overcome barriers that stand in the way of electricity service that could support quality-of-life and economic development improvements, while also saving money.

UNDERGRID MINIGRIDS OFFER A COMPELLING OPPORTUNITY FOR ALL STAKEHOLDERS

For DisCos, undergrid minigrids could slash financial losses associated with underserved communities by at least 60%. Transitioning just 400 communities to undergrid minigrids could reduce a single DisCo's annual financial losses by about ₦1 billion ($3 million). With a distribution usage fee from the minigrid developer, these savings could increase to over ₦2 billion ($6 million) annually for the DisCo.

For minigrid developers, an estimated 40 million rural residents are underserved by the main grid. Of these, close to 35% could be served by over 4,000 commercially viable undergrid minigrid systems. Nationwide, the revenue opportunity from these minigrids is approximately ₦400 billion ($1 billion) per year, offering minigrid developers an annual profit on the order of ₦75 billion ($200 million).

For underserved communities and customers, compared to the status quo energy mix of grid and diesel, residential customers would save an average of ₦54 ($0.15) per kWh. Across Nigeria, transitioning residential undergrid customers to minigrid service could yield ₦60 billion ($170 million) in annual savings. Meanwhile, undergrid minigrid customers benefit from better, more-reliable, cost-effective electricity service.

CHARTING A PATH FORWARD FOR UNDERGRID MINIGRIDS IN NIGERIA AND BEYOND

Each of these stakeholder groups has a role to play in seizing the undergrid minigrid opportunity. Five main steps define the pathway: a) promote minigrid awareness, b) develop business models, c) implement pilot projects, d) enable market growth and scaling, and e) evaluate and ensure benefits. Although this report focuses on Nigeria, the steps and potential opportunity are applicable throughout much of sub-Saharan Africa for the benefit of millions of undergrid customers and the DisCos and minigrid developers that serve them.

1. MINIGRID IMPLEMENTATION UNDER THE GRID IS AN OPPORTUNITY IN NIGERIA

Throughout sub-Saharan Africa, hundreds of millions of people live "under the grid." Such communities are within distribution company (DisCo) territory, but receive unreliable, inconsistent, and/or low-quality power that does not meet their needs—or they receive no power at all. These communities are thus undergrid yet also underserved (see **Box 1**).

There are about as many undergrid customers as off-grid customers (about 200 million households globally in each category).[1] They face many of the same electrification challenges, especially around accessing the development benefits of electricity.[2] However, governments and development partners tend not to focus on undergrid customers because, in theory, they already have at least nominal electricity access.

There is an untapped opportunity to better serve undergrid communities through minigrids that utilize existing distribution and are powered by a suite of distributed energy resources (DERs).[3,i] We call these systems **undergrid minigrids.**

Undergrid minigrids offer an emerging opportunity to profitably improve electricity service in rural communities throughout sub-Saharan Africa.[ii] The Nigerian market offers the enabling conditions required to test and implement these systems, which will result in a stronger, more sustainable, resilient distributed energy base over the long term.

BOX 1

UNDERGRID TERMINOLOGY

- **Undergrid communities** are underserved by DisCos and require improved energy supply—they may receive low-quality or unreliable energy, or may not be actively served but within the DisCo franchise
- **Underserved customers** live in undergrid communities and may or may not have a grid connection
- **Interconnected minigrids** are minigrids operating within DisCo franchise territory, with the option to share distribution assets with the DisCo

This report provides specific context and recommendations based on the Nigerian case, but much of the discussion around the undergrid minigrid opportunity is transferrable to other underserved communities.

Today, Nigerian DisCos face challenges in providing reliable service to rural customers within their territories while covering their costs.[iii] Nigerian utilities have the third-lowest reliability in sub-Saharan Africa; 90% of grid connections are considered unreliable, and outages are longer and more frequent in rural areas.[4]

[i] A minigrid is a self-contained electricity generation and distribution system that provides power at the community level. Minigrids are typically used in rural areas where grid extension is not viable, and usually consist of a combination of solar photovoltaics, battery storage, and a backup diesel generator.

[ii] Undergrid minigrids may be an attractive solution in peri-urban areas as well, but to keep a reasonable scope this report focuses on the opportunity in rural communities.

[iii] The challenges facing power systems in Nigeria and elsewhere in sub-Saharan Africa require a holistic approach to determine least-cost pathways for efficiently improving operational sustainability. The opportunity proposed in this report is one solution that can be implemented in the near term as part of a broader long-term strategy.

The typical undergrid community in Nigeria receives only a few hours of electricity per day from the grid, which struggles to reliably generate, transmit, and distribute power throughout the country—even in the most functional urban service areas. Customers often supplement grid service with expensive and polluting alternatives, ranging from traditional kerosene lamps to petrol or diesel generators. Residents of rural areas often pay over ₦200/kWh ($0.60) for these alternate sources of energy, which is unaffordable for many residents and small business operators.[iv,5]

Undergrid minigrid systems could provide underserved communities with access to high-quality, reliable, and affordable electricity from a different provider, while allowing DisCos to focus investment in high-priority urban areas. Our analysis finds that undergrid minigrids represent a ₦400 billion ($1 billion) annual revenue opportunity in Nigeria today (see **Section 2**). In many cases a minigrid system could supply 24-hour service at a more-affordable tariff than other energy alternatives (see **Figure 1, page 9**).

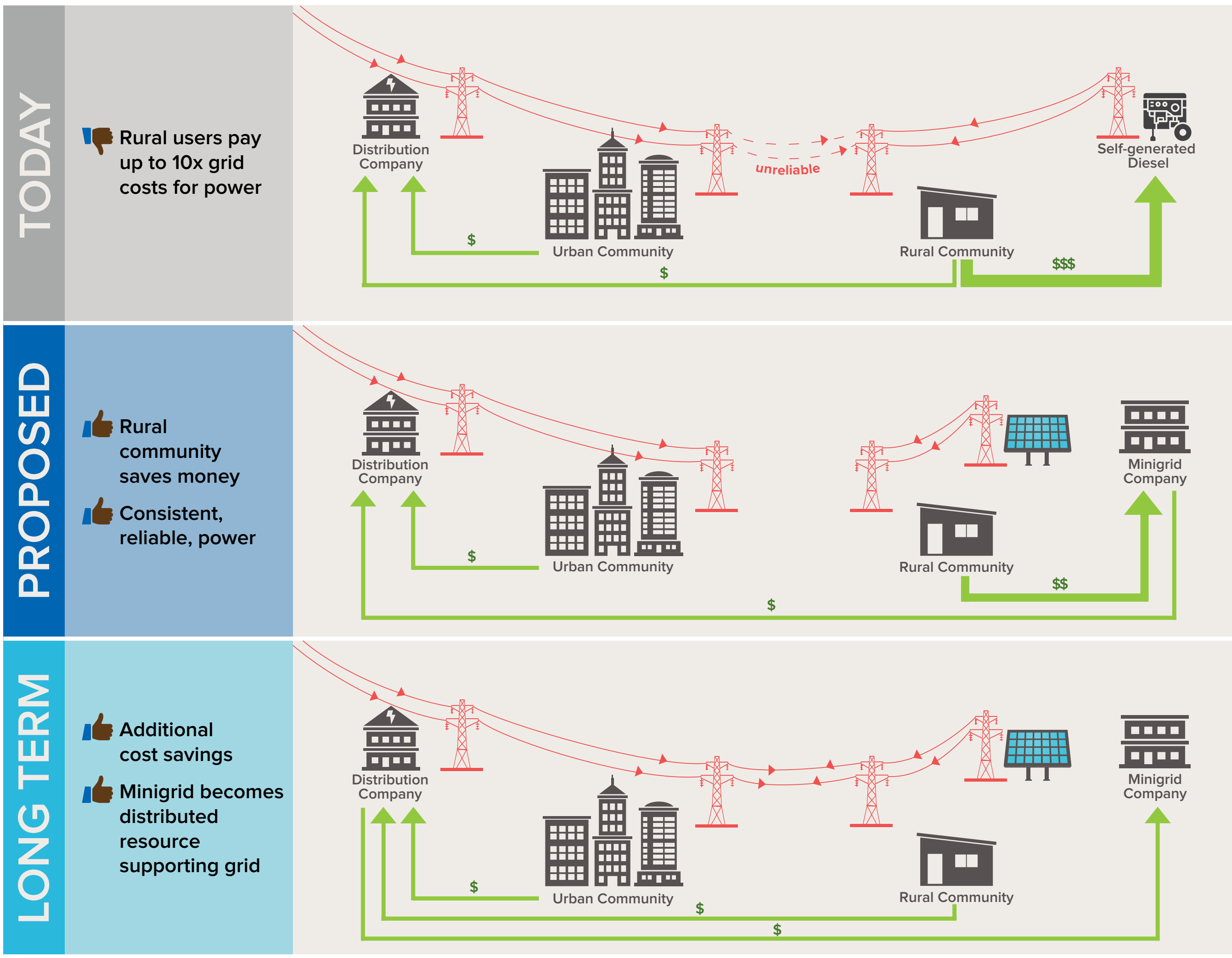
The business model for undergrid minigrid deployment could take many shapes.[v,6] For example, a minigrid could be completely owned and operated by a single developer or by multiple third parties. The minigrid could function as an islanded system, severing ties to the main grid and operating in isolation from or in parallel to it, or could be fully interconnected. With the latter, there are a variety of options for power provision and distribution. For instance, the minigrid could sell excess power to the grid through a power purchase agreement (PPA) or pass through grid power either as backup or whenever it is available. These models have not been tested and will require negotiation to refine.

[iv] We use a rate of US$1= N350 in this report to represent a conservative estimate of the parallel market exchange rate at time of publication, reflecting commercial bank exchange rates and the difficulty of accessing project finance at the Central Bank of Nigeria exchange rate.

[v] These models mimic those existing for grid-interconnected systems elsewhere in the world.

FIGURE 1

INTEGRATING MINIGRIDS IN UNDERGRID COMMUNITIES



Undergrid minigrid deployment can provide reliable electricity and cost savings to rural consumers, who pay up to 10 times the grid tariff rate for diesel or petrol self-generation. In the short term these minigrids can operate in isolation, but long-term grid integration creates a set of distributed energy resources that can trade power with the grid, providing additional benefits including grid resilience.

BOX 2

REGULATORY OPPORTUNITY FOR UNDERGRID PROJECT DEVELOPMENT IN NIGERIA

The Nigerian Electricity Regulatory Commission (NERC) has established regulations allowing private companies to work within the franchise territory of a DisCo to offer electricity services to customers.

- A **meter asset provider** can finance and provide meters for DisCo customers. The 2018 regulation creates an independent and competitive metering market to address the national shortage of nearly 5 million meters.[8]
- Up to 1 MW, **minigrids** may operate through a simplified regulatory regime. The tripartite contract (see **Section 2**) allows operation within the territory of a DisCo if the DisCo agrees and a particular community is underserved.[9]
- From 1 MW to 20 MW, **embedded generation systems** may access DisCo networks and customers with the collaboration and partnership of the DisCo. These systems require a business separation with the embedded generation provider holding a generation license, while the DisCo maintains its independent distribution license.[10]
- **Eligible customers** can seek service through an alternative provider. These are customers (or a group of customers) who average consumption above 2 MW and can be metered at a single point. Service providers can use existing distribution assets, which may require an agreement with the DisCo, and are allowed to charge a cost-reflective tariff.[11]

Nigeria is a promising testing ground for undergrid minigrid implementation, and the government's commitment to increase electricity access and reliability has been demonstrated through significant support for undergrid efforts (see **Box 2**). Undergrid minigrids can directly support the stated policy goals of the Nigerian government (described in **Section 5**), which has created the regulatory clarity and policy support to enable undergrid projects.[7]

Undergrid minigrids offer a compelling opportunity to strengthen utility services through an integrated approach that combines on- and off-grid resources to enhance the power sector's resilience. Over time, the integration of these minigrids with grid assets will provide a suite of DERs accessible to the main grid (see **Figure 1, page 9**).[vi] Further, minigrid deployment will introduce additional benefits such as additional distribution infrastructure, new metering assets, and strengthened customer relations. The undergrid opportunity is near-term, actionable, and can address a specific market segment while supporting the vision for a sustainable, reliable, and affordable energy future in Africa.[12]

[vi] In the future, structures for compensating and operating DERs will be required, as have been developed in countries with high penetrations of these resources.

2. BUSINESS OPPORTUNITY FOR NIGERIAN DISTRIBUTION COMPANIES

Today, DisCos in Nigeria incur high financial losses, especially in rural areas. Current tariffs are not cost-reflective, while high aggregate technical, commercial, and collection (ATC&C) losses prevent DisCos from recovering costs and making a return in much of the country. In other words, DisCos are losing money while failing to deliver the electricity service customers need.

However, DisCos have an opportunity to collaborate with minigrid developers in rural communities to address one aspect of this challenge. This would open the door to reducing financial losses by upward of 50% (see **Section 2.2**) and access additional revenue opportunities through a distribution usage fee—a single DisCo in Nigeria introducing an undergrid minigrid model in 400 communities could increase profitability by ₦1 billion ($3 million) or more per year (see **Section 2.2**).[13]

NERC regulations allow for an undergrid minigrid to be constructed and operated within DisCo territory, utilizing existing distribution infrastructure. An interconnected minigrid can operate as an island or could interconnect to the conventional utility grid to buy or sell electricity. Regulation allows for the minigrid to charge cost-reflective tariffs, enabling greater cost recovery and return on investment than the main grid today.[14]

DISCOS CURRENTLY INCUR LOSSES TO SERVE RURAL COMMUNITIES

According to Nigeria's Electricity Sector Reform Act of 2005, DisCo tariff portfolios should be cost-reflective—total revenue per total energy delivered should cover the cost of energy, transmission and distribution costs, and other expenses including operation, return on capital, and repayment of debt.[15] Tariffs today are not cost-reflective due to constraints on raising tariffs and underestimation of commercial losses in tariff calculation models.

The combination of high technical and non-technical losses, along with tariffs often below actual cost, limit the economic viability of DisCos to serve customers throughout their franchise territories. DisCos are currently unable to effectively recover costs—across the country, revenue covers only 35% of total costs. An average cost-reflective tariff would need to be over ₦40/kWh ($0.12) (see **Table 1, page 12**).[16] Revenue collected covers less than half of incurred distribution expenses.[vii]

[vii] This analysis is based on 2017 cost figures, as tariff-setting has not yet advanced to the model defined in Multi-Year Tariff Order (MYTO) 2018.

TABLE 1

TARIFF ALLOCATION

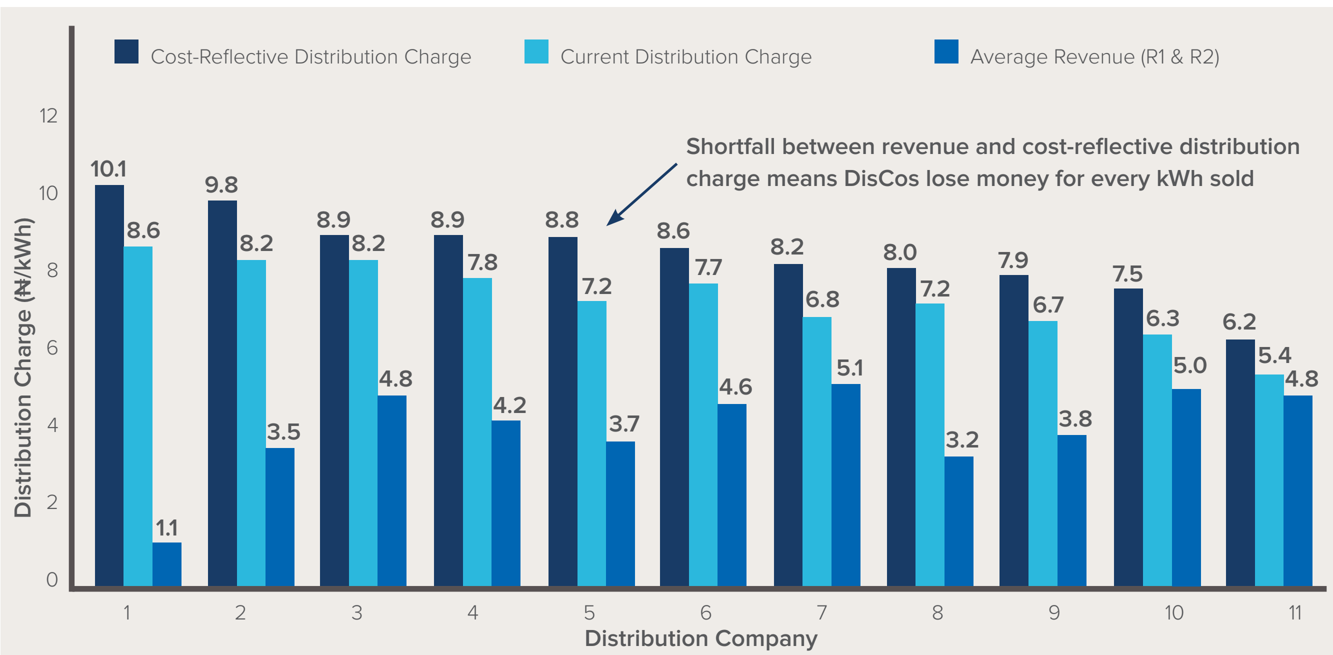
	MYTO ALLOWED TARIFF (₦/kWh)	COST-REFLECTIVE TARIFF (₦/kWh)	ACTUAL REVENUE* (₦/kWh)
GENERATION	12.0 ($0.03)	19.4 ($0.06)	6.43 ($0.02)
TRANSMISSION	5.1 ($0.01)	7.8 ($0.02)	2.72 ($0.01)
DISTRIBUTION	12.2 ($0.03)	13.7 ($0.04)	6.52 ($0.02)
TOTAL	29.3 ($0.08)	40.9 ($0.12)	15.67 ($0.04)

* Including all technical and non-technical losses

Multi-year tariff order (MYTO) costs, actual revenue allocation, and cost-reflective (CR) charges for generation, transmission, and distribution components of the Nigerian electricity system.[17] On average, actual revenue covers about 35% of calculated costs for Nigerian DisCos.

FIGURE 2

COST-REFLECTIVE VS. ACTUAL DISTRIBUTION CHARGE



The difference between current distribution charge, cost-reflective distribution charge, and revenue available to cover distribution costs today demonstrates that revenue allocated distribution charge would need to nearly triple to cover actual expenses.[20] Average revenue is weighted by the number of R1 and R2 customers, and DisCos are numbered for anonymity.

The distribution portion of revenue expectation can be used to evaluate the cost-reflective distribution charge that would enable the DisCo to cover costs and earn a reasonable return for investors. Today, residential tariffs are currently fixed at ₦4/kWh and ₦29/kWh ($0.01 and $0.07, averaged across DisCos) for R1 and R2 customers respectively.[viii,18] Combined with reportedly low collection rates, these residential customers collectively contribute only ₦4/kWh to the ₦8/kWh incurred as distribution expense.[19] **Figure 2, page 12** shows the difference between distribution-related revenue from current tariffs and a cost-reflective distribution charge.

Rural areas are a particular challenge for DisCos due to the high losses that result from non-cost-reflective tariffs and low collection rates. Commercial losses are highest in rural areas, where collection estimates for the unmetered connections that make up the majority of rural customers are roughly 30% and even lower in practice due to electricity theft through meter bypassing.[ix] Accounting for these non-technical losses and given current service levels, DisCo tariffs would need to be 10 times higher than the R2 tariff to break even in many communities today (see **Figure 3, page 14**). Alternately, DisCos would need 100% collection and 24-hour service to break even on today's R2 tariff.

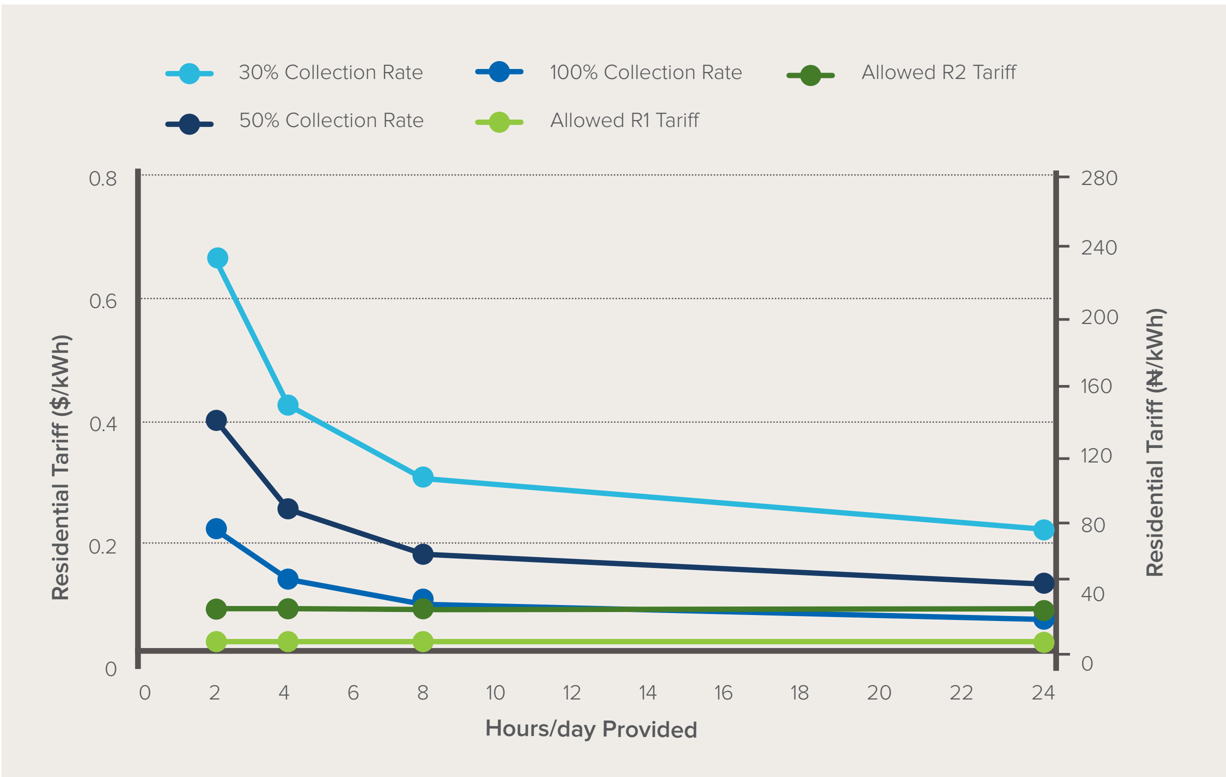
There is clearly a strong economic case for DisCos to find a better service model for rural customers. Installing meters and improving collections is one option for doing so, along with infrastructure rehabilitation, and is already being pursued. Exploring the development of undergrid minigrids is another promising option that should be considered alongside these efforts and may offer quicker improvement in both service provision and revenue collection.

[viii] R1 customers are defined as households consuming less than 50 kWh per month, while R2 customers consume more than 50 kWh per month and comprise the majority of residential connections in Nigeria. RMI site visits have found that customers in rural communities are currently billed at either R1 or R2 rates.

[ix] This collection rate is derived from personal communication with a number of aggregated and anonymized DisCos.

FIGURE 3

TARIFF TO BREAK EVEN



Residential tariffs required for DisCo to break even in a typical undergrid community,[x] based on conservative estimates of today's cost-to-serve in remote rural areas.[xi] At current levels of daily electricity service (less than 6 hours) and collection rates (30%), there is significant opportunity for solutions like undergrid minigrids to bridge the gap between revenue and cost-reflective connections (as discussed in **Section 2.2**). Conversely, as customer collection rates increase and the grid provides more reliable service, reinforcing and strengthening the grid may be the best option for improving electricity quality.[21]

[x] Based on internal modelling, assuming the ratio of residential to commercial tariffs remains consistent with rural tariffs today and collection rates for commercial customers are 60% greater due to more frequent metering.

[xi] Including the cost of power and DisCo operating expenses, distribution, customer service, billing, and management, and depreciation of distribution assets.

2.2 UNDERGRID MINIGRIDS SAVE 60% OR MORE FOR AN ILLUSTRATIVE DISCO

Incorporating undergrid minigrids within a DisCo's network directly supports several core business objectives: a) optimizing network expansion investments, b) reducing ATC&C losses, and c) meeting performance targets to improve investment potential. Meanwhile, third-party minigrid developers can install or improve the local infrastructure for supplying electricity at cost-reflective tariffs.

Current residential electricity tariffs leave a shortfall between actual DisCo revenue and cost-reflective tariffs (see **Figure 2, page 12**). In theory, the revenue shortfall from the poorest customers (on low-consumption tariffs) could be cross-subsidized by other customers. This is not the reality because those other tariffs are not cost-reflective either. This leaves DisCos with a need for new mechanisms for reducing the revenue losses in rural areas. Undergrid minigrids offer one such mechanism.

Consider the following: a typical rural undergrid community might have 4,500 residents and receive power from the grid for an average of two hours per day. These customers are unmetered, and on average the DisCo is able to collect just 30% of estimated bills. At the same time, the DisCo is incurring fixed management and operations costs to serve the community. In other words, the DisCo is providing electricity for which it is largely not paid (i.e., "free" electricity), while shouldering other costs for which it does not receive compensating revenue.

Underserved undergrid communities represent consistent financial losses for DisCos. They are a cost centre, when they should be a modest profit centre, or at least revenue neutral. In this scenario today, the DisCo is likely losing an average of ₦72 ($0.21) per kWh distributed.[xii] This equates to a loss of about ₦7,000 ($19) per connection per year or ₦7.8 million ($22,000) per community per year.[xiii]

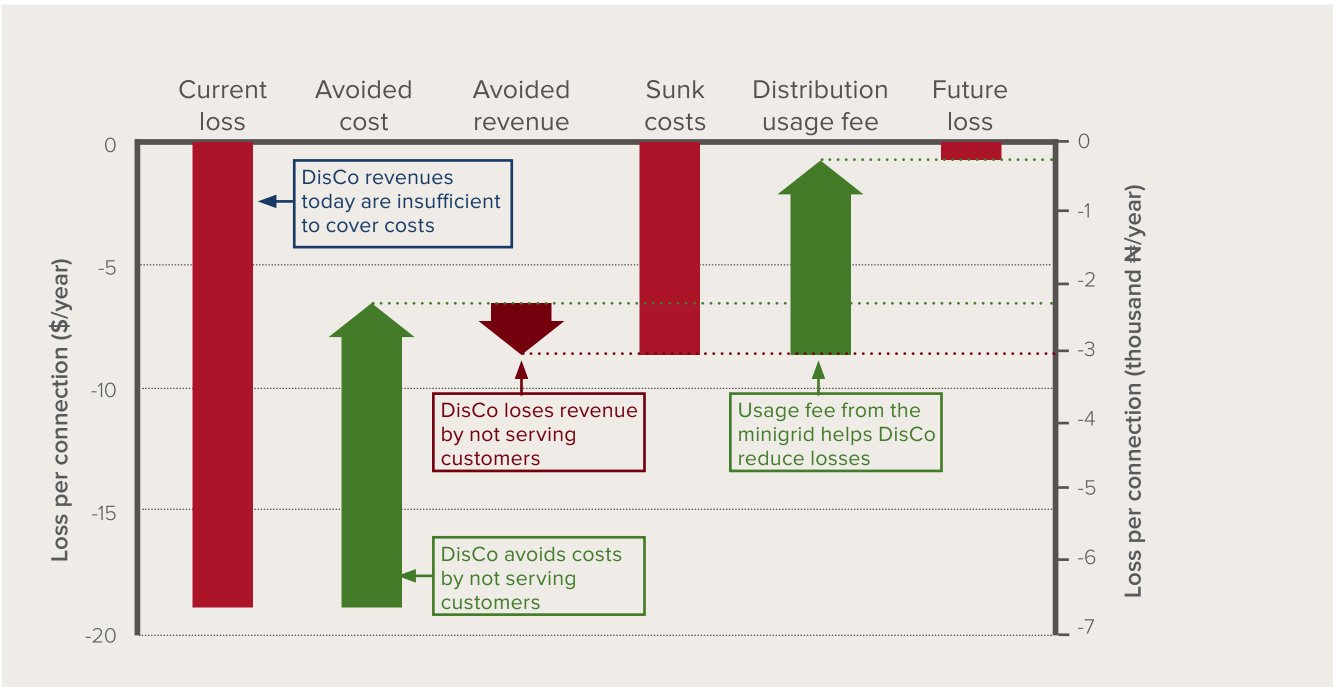
Undergrid minigrids could help DisCos reduce these financial losses by transferring the collections responsibility (and risk) to minigrid operators, while also collecting a distribution usage fee for sharing distribution infrastructure with the minigrid. While DisCos are not currently covering their costs, and struggle to invest the capital required in metering all customers, the independent minigrid operator can charge a cost-reflective tariff and install metering solutions to minimize collections losses.

[xii] Losses reported here, based on DisCo financial statements, are higher than those calculated from tariff rates in section 2.1. This indicates lower revenue per kWh (e.g., from greater meter bypassing or lower collections) or higher costs (e.g., from relatively high overhead) in rural communities than are estimated for the full country based on MYTO.

[xiii] Assuming the DisCo serves an average residential load of 0.12 kWh/hr for two hours per day.

FIGURE 4

UNDERGRID MINIGRID: CHANGE IN PROFITABILITY



For a single illustrative community, the distribution company can avoid 50% of current financial losses by agreeing with a minigrid developer to serve the community.[23] Today's losses can be mitigated by eliminating the costs of bulk power purchase, distribution, and variable operating expenses. Even not serving the community, the DisCo will retain some sunk costs, including overhead, debt, and asset depreciation. The DisCo will save, on average, a minimum of ₦4,300 ($12) per connection through an undergrid minigrid. Additional savings through a usage fee (with a representative value shown here) further improve the finances.

2.3 SCALING POTENTIAL OF THE UNDERGRID SOLUTION

As **Figure 4** demonstrates, a DisCo could cut financial losses by 50% by halting its own service and "divesting" electricity delivery and billing to a third-party minigrid developer for a given underserved community for a period of time, even after taking into account lost revenue from that community.[xiv] Meanwhile, the minigrid operator could implement a cost-reflective tariff structure that enables a profitable business model while better serving the community. The DisCo could further offset its remaining sunk costs through a distribution usage fee that moves the DisCo even closer to profitability in these areas.

Transitioning 400 communities to undergrid minigrids could reduce a single DisCo's annual financial losses by about ₦1 billion ($3 million). With a distribution usage fee, these savings could increase to over ₦2 billion ($6 million) annually (see **Appendix 2**).[xv] In the longer term, establishing the true cost of providing electricity service in Nigeria may help DisCos to make a case for their tariffs to be increased to cost-reflective levels.

On the minigrid developer side, an estimated 40 million rural residents are underserved by the main grid. Of these, close to 35% could be served by over 4,000 commercially viable undergrid minigrid systems.[24] Nationwide, the revenue opportunity from these minigrids is approximately ₦400 billion ($1 billion) per year, offering minigrid developers an annual profit on the order of N75 billion ($200 million) (see **Appendix 1**).[xvi]

2.4 UNDERGRID MINIGRIDS ARE ATTRACTIVE TO CUSTOMERS

Rural consumers value many factors of electricity service, including cost, reliability, quality (e.g., stable voltage and frequency), customer service, and the accuracy and transparency of billing.[25] Minigrids perform well across these areas, making them attractive despite their higher price relative to electricity from the grid. Conversely, the centralized grid—while cheaper than other choices—often provides low reliability and power quality (see **Section 3.1**).

By offering an attractive power solution to serve rural customers, DisCos will improve the reputation of the energy services they provide. Minigrid projects can provide better customer service and greater transparency due to more effective local operations with local representatives in or near host communities, which makes customers more likely to pay for electricity services received.[26] The prevalence of prepaid metering systems gives minigrid customers additional insight into and confidence in the billing process.

Further, minigrid service levels are required by the NERC Mini Grid Regulation to meet certain minimum standards, which outperform available grid service—increasing customer willingness to pay.[27] Since commercial losses are largely driven by customer non-payment, growing customer satisfaction—and the resulting improvements in customer retention and willingness to pay bills—will strengthen the DisCo business.

[xiv] Financial losses shown include the cost of power and DisCo operating expenses, including the cost of distribution, customer service and billing, and management, and depreciation of distribution assets.

[xv] The distribution usage fee here is calculated to recover costs for the DisCo.

[xvi] Assuming tier 3 household consumption and minigrids sized to serve an average community population of 4,500, generating a 15% IRR.

Finally, the addition of DERs in the form of minigrids (see **Figure 1, page 9**) will provide a mechanism to increase available electricity supply without straining limited transmission capacity. The integration of minigrids into the main grid will provide DisCos with an additional set of local generation and distribution resources, improve sector resiliency, and decrease losses.

2.5 RISKS TO THE DISCO

The implementation of undergrid minigrids would represent a new strategy for DisCos. Because the financial burden of this strategy falls largely on the minigrid developer, the greatest risk to the DisCo has to do with customer engagement and retention. The temporary loss of customer engagement when minigrids are used to serve rural communities could affect the DisCo over the long term, since customer preferences and expectations could change during this time period. It could be challenging to bring customers back to DisCo service in the future once they have been transitioned to a minigrid service model.

3. COMMUNITIES SAVE WITH UNDERGRID MINIGRIDS

Many rural undergrid communities may prefer to be served by a minigrid since it can provide more reliable and higher-quality service than the grid and can be less expensive and cleaner than alternatives. Undergrid minigrids have the potential to serve thousands of rural communities that are underserved and pay high costs for kerosene and diesel generation to supplement unreliable or unavailable grid power. In a typical community, residential customers would save an average of ₦54 ($0.15) per kWh while accessing additional benefits of reliable electricity service. Across Nigeria, transitioning residential undergrid customers to minigrid service could yield ₦60 billion ($170 million) in annual savings.[xvii, 28]

3.1. MINIGRID ECONOMICS CAN WIN AT THE COMMUNITY LEVEL

Nigerian consumers use a variety of electricity service options. Grid connection, petrol or diesel gensets, solar home systems, and minigrids are all in use and provide a range of available service levels. These can be differentiated by upfront cost, ongoing cost (experienced as a per-kWh tariff or daily fee), and reliability or availability; and customers can match their electricity needs with the best suited option (see **Figure 5, page 20**). For instance, solar home systems can be an effective resource where only a low level of service is required or there is low density of use. But while they offer a more affordable upfront cost, solar home systems are relatively expensive on a per-kWh basis and generally lack the capacity to power the productive-use machinery that drives local economies.

Commercial customers require power that is predictable and stable and allows them to run equipment like welding or milling machines. Today, many of these customers rely on expensive energy alternatives such as diesel generators to supplement their average two hours per day of grid power,[29] paying a blended average cost of electricity of approximately ₦185 ($0.53) per kWh.[30] Consumers with petrol generators likely experience similar costs,[31] and average community-wide costs are around ₦205 ($0.58) per kWh when alternatives including kerosene are accounted for.

Conversely, in many underserved parts of Nigeria, minigrids can provide a cost-effective, reliable alternative to today's sources of power. The cost savings enabled through distribution sharing and economically active communities puts undergrid minigrid tariffs for least-cost solar-diesel-battery systems at ₦150 ($0.45) per kWh.[xviii] This is clearly within both Nigerian households' and commercial customers' ability to pay, since the average tariff of operational commercial minigrids, at ₦200 ($0.57) per kWh, has already proven to be competitive in communities throughout the country.[32]

[xvii] Customer savings are computed from the blended cost of power today from grid connections, kerosene, and generator costs, conservatively assuming consumption of 1 kWh/day per connection. Savings would be closer to $0.08/kWh for a customer transitioning from a generator to minigrid service. Market sizing assumes 3 million households are transitioned to minigrid service in undergrid communities.

[xviii] Based on internal modelling assuming similar hardware costs to minigrids commissioned in Nigeria in 2017, soft costs consistent with current best practices, no distribution expense, and 15% IRR over a 20-year system lifetime.

FIGURE 5

COMPARISON OF ELECTRICITY OPTIONS FROM CUSTOMER PERSPECTIVE

	COST OF CONNECTION (UP-FRONT COST)	COST OF ELECTRICITY (ONGOING COST)	AVAILABILITY AND RELIABILITY	ABILITY TO SUPPORT PRODUCTIVE-USE EQUIPMENT
MAIN GRID	●	●	○	◑
MINIGRID	◑	◑	●	●
SOLAR HOME SYSTEM	◑	○	◕	◔
DIESEL OR PETROL SELF-GENERATION	○	◔	◑	◕

● Highest-performing ○ Lowest-performing

The suite of energy alternatives available in Nigeria today offers customers the ability to match a solution to their needs. Overall, considering the attributes of low connection cost, low tariff, availability, and ability to drive productive uses of energy, minigrids offer the most consistently high-performing solution.

Residential tier 3 and 4 energy users transitioning from small generating systems to minigrid service would save 15% on energy expenditures, or approximately ₦50,000 ($150) annually.[xix] Minigrid developers' rapid adoption of key cost-reduction opportunities will further increase both minigrid affordability and customer savings.[xx]

3.2 COMMUNITY DEVELOPMENT THROUGH MINIGRID DEPLOYMENT

Customers in undergrid communities tend to have greater electricity demand than their counterparts in off-grid communities due to proximity to urban centres and high commercial productive use. Minigrid implementation will generate savings for these

[xix] Tier 3 and 4 users are defined as consuming 1.0–3.4 and 3.4–8.2 kWh per day, respectively, in the Multi-Tier Framework (Beyond Connections: Energy Access Redefined, Energy Sector Management Assistance Program, 2015).

[xx] Cost-reduction opportunities are detailed RMI's forthcoming report *Minigrids in the Money: Six Ways to Reduce Minigrid Costs by 60% for Rural Electrification.*

commercial users, which can drive local economic growth and development.[33] For example, the availability of reliable and affordable electricity has been shown to drive rural Nigerian entrepreneurs to invest in equipment, such as mills, that increase their economic productivity.[34] Job creation through entrepreneurial growth or with the minigrid company offers opportunities for local youth. Further, lower costs paired with local development and increased economic activity will reinforce the ability of customers to purchase power.[35]

3.3 RISKS TO THE COMMUNITY

Despite the benefits, minigrids currently remain more expensive than power from the grid alone. A community will need to weigh these factors, along with the potential risk of entering a long-term tripartite contract with the DisCo and minigrid provider. For example, on an economic basis it makes sense for a community to agree to a 10-year tripartite contract for minigrid service if it expects to receive less than 40% reliability or 10 hours of power from the grid per day for at least three years.[xxi]

While different implementation pathways for undergrid projects are still being explored, one mechanism to address this would be to allow customers the option of continuing to buy power from the grid at current costs and constrained availability as well as to purchase additional service through the minigrid developer. Ultimately, if the cost of minigrid service disincentivizes consumers from using power, this could constrain local economic growth.

[xxi] The length of a tripartite contract required to develop an undergrid minigrid system is not stipulated in the Mini Grid Regulations (20 years is suggested as a starting point), so the 10-year term indicated here is only an example.

4. UNDERGRID MINIGRIDS OFFER AN ATTRACTIVE INVESTMENT OPPORTUNITY FOR DEVELOPERS

Commercial minigrid developers—as smaller, local, and more-agile companies than DisCos—can drive undergrid market growth and success. In exchange for the added complexity of partnering with a DisCo, minigrid developers could access a market worth approximately ₦400 billion ($1 billion) in annual revenue (see **Section 2.2**).

4.1 MINIGRID DEVELOPERS ALSO BENEFIT FROM THE UNDERGRID OPPORTUNITY

Undergrid minigrids offer a promising business opportunity for minigrid developers, investors, and operators. The provision in Nigeria's Mini Grid Regulation for cost-reflective minigrid tariff structures, including for interconnected systems, makes it possible for developers to profitably deploy undergrid minigrid systems. While not without risk, these can largely be managed through establishing agreeable tripartite contract terms before project development.

The synergies between DisCo resources and minigrid systems make the minigrid business model—which is already viable for isolated systems—potentially even more attractive in many undergrid communities.[36] Greater economic activity and ability to pay in undergrid communities (see **Section 3**) offers greater revenue opportunities. Further, sharing distribution with the utility could save $75,000 for a 100 kW site, decreasing minigrid project capital expenditures by 12% and lowering tariffs by $0.03/kWh.[xxii] The developer's rate of return could be decreased by a percentage point depending on the distribution usage fee that the developer pays to the DisCo (see **Appendix 2**).

The local economic growth enabled through undergrid minigrid implementation strengthens the business case for minigrids. As general community well-being increases, customer demand and ability to pay for minigrid services should rise as well. For example, the increased economic productivity of commercial users due to high-quality, reliable power can drive demand for more electricity from the minigrid. Furthermore, compared with existing grid service, collection rates for minigrids operating under the grid are expected to be significantly higher because customers will be satisfied with the quality of power received and the accuracy of billing and are accountable to a service provider with whom they have better communications and an existing agreement about cost of power and payment requirements. Finally, undergrid minigrids offer the opportunity to test new business models that offer significant scaling potential due to market size and the desire of the Federal Government of Nigeria and donor partners to provide grid-level power throughout the country.

4.2 RISKS TO THE DEVELOPER

The financial success of a minigrid system depends on the developer's ability to pay back upfront investments and operating costs over the system lifetime, which is usually assumed to be 20–25 years. If this system lifetime is longer than the length of the tripartite contract—the duration of minigrid operation—developers risk failing to make a return on their investment. In addition, minigrid system payback could be further threatened by economic downturn or if customers are unable or unwilling to pay electricity bills as anticipated. As with all off-grid development, developers can mitigate this risk by selecting communities where customers have sufficient purchasing power to sustain the project.

[xxii] Calculations assume a constant 15% project IRR and 20-year project lifetime.

Developers also may face challenges in working with DisCos to identify appropriate undergrid sites that offer a strong business case for minigrid development and achieve favourable contract terms. DisCos are required to develop Performance Improvement Plans as well as five-year network expansion plans, which are to be shared with and approved by NERC. These plans can be requested by undergrid minigrid investors/developers and may allow them to identify areas that are available for development. However, negotiation with both the DisCo and the communities will be needed; and the implementation of tripartite contracts may be a slow process in practice.

5. CONNECTION TO NIGERIA'S POLICY OBJECTIVES

Undergrid minigrids can support the policy goals of the Federal Government of Nigeria (FGN) in several ways:

- The FGN, particularly the Federal Ministry of Power, Works, and Housing, has demonstrated a commitment to improved power quality due to the many quality-of-life benefits it brings, including economic, education, and health outcomes. Minigrids are clearly relevant to FGN policies and regulation that promote electricity access and power quality, such as the Economic Recovery and Growth Plan (ERGP), Power Sector Recovery Programme (PSRP), and National Renewable Energy and Energy Efficiency Policy (NREEEP).

- Minigrids are also a core component to recent work by the Rural Electrification Agency (REA) and its Off-Grid Electrification Strategy.

- Finally, minigrids support the SE4ALL Action Agenda, which sets Nigeria's energy mix and renewables targets, and the country's attainment of its intended nationally determined contribution (INDC) and climate policy targets.

The co-benefits of undergrid minigrid projects also align with government policies on economic, educational, health, and other outcomes. Undergrid minigrids can be the means towards achievement of the ambitious targets laid out in these policies and dramatically change day-to-day life in many currently underserved communities.

5.1 ENERGY POLICY IMPERATIVE

Undergrid minigrids would require an investment in local infrastructure, which is a focus of both the ERGP and NREEEP. The ERGP, released in 2017, emphasizes investment in infrastructure with power being a most important element of this plan.[37] The plan includes the implementation of the PSRP, which was developed by FGN in partnership with the World Bank.[38] FGN also developed the NREEEP to ensure the **sustainable** development of power infrastructure, which strategizes for the electrification of remote rural areas with off-grid solutions that entail utilisation of renewable energy sources.[39]

The implementation of undergrid minigrids would increase power in rural communities and enable a rise in economic activities, supporting the ERGP's objectives. Further, this development would also enable achievement of ambitious goals by the REA to develop 10,000 minigrids in Nigeria by 2023 and develop an off-grid model for serving rural parts of Nigeria.[40] To date, off-grid efforts by the REA include efforts to energize economies through work in markets in Ondo, Kano, Lagos, Ogun, Oyo, and Abia States and support for minigrid development through the Rural Electrification Fund.

5.2 POLICY SUPPORT FOR CO-BENEFITS OF MINIGRID PROJECTS

Undergrid minigrids may also contribute to health, environmental, education, and economic outcomes in local communities, in support of several additional policies in Nigeria. A partial list of these policies, along with the contribution of the minigrid systems to relevant outcomes, is included in **Table 2**.

TABLE 2

UNDERGRID MINIGRIDS OFFER BENEFITS TO A RANGE OF SOCIAL POLICIES IN NIGERIA

POLICY	OUTCOME	MINIGRID CONTRIBUTION
NATIONAL HEALTH POLICY (2016)[41]	Improved maternal and child health; control of diseases; emergency response	Consistent electricity access will make it possible to provide emergency care at night and refrigerate vaccines
NATIONAL POLICY ON ENVIRONMENT (2016)[42]	Reduced air pollution and noise pollution and mitigation of climate change	With most power coming from a solar array and battery bank, the pollution associated with petrol and diesel generators will fall
NATIONAL POLICY ON EDUCATION	Improved academic performance	Children can study more in the evening with a clean, reliable lighting source and educational outcomes should improve
NATIONAL POVERTY ERADICATION PROGRAM; RURAL INFRASTRUCTURES DEVELOPMENT SCHEME	Local economic growth	Affordable, reliable electricity will increase productive end uses of electricity
NIGERIA POLICY ON CLIMATE CHANGE[43]	Low-carbon strategy and sustainable economic growth	Renewables-based minigrids offer economic development with low carbon emissions
NATIONAL POLICY ON MICRO, SMALL AND MEDIUM ENTERPRISES (MSME)[44]	MSME and economic growth, employment, and wealth generation	Affordable, reliable electricity can increase commercial development and drive local economies

6. RECOMMENDED PATH FORWARD

Stakeholders have an excellent opportunity to enable undergrid minigrids to become a successful part of an integrated approach to energy planning in Nigeria. Government and regulators, distribution companies and minigrid developers, and—most importantly—communities can work together to mutual benefit to make this happen. However, perfect need not be the enemy of the good—existing policy allows interested stakeholders to begin experimentation today.

This section describes the roles of different stakeholders along a five-step path to pursue the undergrid minigrid opportunity (see **Table 3**).[xxiii] The majority of these recommendations are applicable beyond Nigeria, although some assumptions underlying the current status or roles of the regulator, government, and DisCo may be country-specific.

STEP 1: PROMOTE MINIGRID AWARENESS

To ensure undergrid minigrid success, a large set of stake-holders can coordinate to educate the market and incentiv-ize implementation. Greater transparency of information and processes will drive successful projects by allowing these stakeholders to work together more effectively.

DisCo Support: Each DisCo can create a hub, in the form of a minigrid desk, to coordinate minigrid activities within its territory. This would enable communication with developers, facilitate public awareness, and enable access to expansion plans. DisCos can identify and map territories that they are willing to make available to undergrid minigrids, such as those with high ATC&C losses and low reliability.

Minigrid Developer Support: Developers can support sensitivity trainings and community-level outreach efforts to increase awareness and acceptance of minigrid projects.

Government/Regulator Support: REA's Promotion Department can use exposure, outreach, and sensitivity training to begin increasing buy-in from relevant stakeholders and increase local community engagement. The FGN can support DisCo minigrid desk setup, and REA and NERC can monitor minigrid market growth through these desks by ensuring that key performance areas are set and measured and that parties are held accountable.

STEP 2: DEVELOP BUSINESS MODELS

Because undergrid minigrids are a yet untested strategy for rural development, there are several open questions as to how these projects will be best implemented. Different business models and ownership structures should be evaluated before projects are actually deployed. The resulting model will be informed by convergence on a mutually beneficial tripartite contract, which will lay out roles, ownership rights, and the term for minigrid operation within DisCo territory.

DisCo Support: To inform the development of an acceptable tripartite contract and a clear undergrid business model, DisCos will need to perform internal evaluation of their cost structure and revenues in rural communities that they serve. Understanding the source of current financial losses in rural areas will allow DisCos to assess the applicability of undergrid minigrids to different communities, permitting the identification of communities whose development will mutually benefit DisCos, developers, and the community.

Minigrid Developer Support: Similarly, minigrid developers can evaluate their own cost and revenue structures to apply to undergrid communities to help determine an appropriate undergrid minigrid model and tripartite contract.

Government/Regulator Support: The government, particularly REA and NERC, can act as an objective third-party arbiter to convene and facilitate discussions

[xxiii] Note that these recommendations are specific to undergrid minigrids. For broader activities, such as sharing existing DisCo grid extension plans or reducing hardware procurement costs, see the 2018 NESG and RMI Minigrid Investment Report.

among communities, DisCos, and minigrid developers. Further, NERC can continue to clarify regulations to inform tripartite contract terms, such as expectations for asset ownership at the conclusion of the contract term.

STEP 3: IMPLEMENT UNDERGRID MINIGRID PILOT PROJECTS

Pilot projects are a first, necessary, and concrete step to prove the case for undergrid minigrid development. The demonstration of bankable projects is required to build investor confidence. DisCos, developers, and the government should undertake a good-faith effort to test pilot projects in order to fully understand the opportunity present.

DisCo Support: DisCos can collect and share data on undergrid minigrids to inform investors, improve business models, and identify the commercial viability of different minigrid profiles.

Minigrid Developer Support: Separate from DisCo data sharing, minigrid developers can collect and share data on system performance to build understanding of the social and economic viability of minigrids in Nigeria.

Government/Regulator Support: Working with development partners, the government can provide financial support for the development and connection cost for minigrids through grants, subsidies, and other efforts to backstop risk in pilot projects until the market is self-sustaining. NERC can expedite necessary permits and licensing, while REA can link with existing efforts to support site identification, project planning, and ongoing monitoring.

STEP 4: ENABLE MARKET GROWTH

Undergrid minigrids can be implemented in thousands of communities to support local community development through improved electricity service, relieve DisCo losses, and drive the minigrid sector. With market growth, the addressable market will increase due to economies of scale and ongoing cost reduction. The government, DisCos, and developers can each offer support to ensure effective scaling.

DisCo Support: DisCos can help allay investor concerns by updating expansion plans and by planning solicited and unsolicited bidding processes to encourage and coordinate undergrid minigrid development within their network. They can also draft commercial documents defining joint venture agreements, network validation, and tariff sharing to avoid delays working with minigrid developers.

Minigrid Developer Support: Developers can build investor confidence and raise capital for projects by demonstrating successful pilot programs and bankable projects.

Government/Regulator Support: The government can improve investor confidence by ensuring integrated expansion planning for both on-grid and off-grid communities. This integrated energy system approach can support broader cost-effectiveness and efficiency of grid improvement and energy access efforts.

STEP 5: EVALUATE AND ENSURE BENEFITS

As the sector grows and matures it will be important to ensure that projects are delivering on the promise to improve access to affordable and reliable power.

DisCo Support: Companies can document the successes and challenges experienced with projects on an ongoing basis to provide lessons learned that can shape the sector's approach and the way DisCos approach grid expansion and rehabilitation in the future.

Minigrid Developer Support: Like DisCos, developers can also document and build on lessons learned from project experience.

Government/Regulator Support: FGN, and especially NERC, can review project performance to ensure that they are delivering promised benefits to customers and meeting required standards. Building on these findings, NERC can adjust regulations as needed to maximize the effectiveness of future projects towards achieving policy goals.

TABLE 3
STEPS TO PURSUE THE UNDERGRID MINIGRID OPPORTUNITY

	DISCO	MINIGRID DEVELOPER	GOVERNMENT/REGULATOR
STEP 1: PROMOTE MINIGRID AWARENESS	• Implement centralized minigrid desk • Develop and provide network expansion plans • Map undergrid communities by identifying rural areas with high ATC&C losses	• Support sensitivity trainings and community-level outreach efforts	• Conduct outreach and sensitivity training • Support DisCo development of minigrid desk • Ensure key performance areas drive growth • Develop community engagement plans • Share existing grid extension project sites
STEP 2: DEVELOP BUSINESS MODELS	• Evaluate cost structure and revenues in rural communities	• Evaluate minigrid project finances to develop undergrid in collaboration with community and DisCo	• Approve appropriate use of system charges and tripartite contract
STEP 3: IMPLEMENT PILOT PROJECTS	• Share data to increase investment and improve business models	• Share system performance data to assess viability	• Provide grants and subsidies to lower cost of connection • Expedite licensing process
STEP 4: ENABLE MARKET GROWTH	• Publish expansion plans and other documents to increase transparency • Develop process for minigrid project proposals	• Introduce cost-reduction and community engagement strategies • Document project bankability	• Integrate on- and off-grid system planning
STEP 5: EVALUATE AND ENSURE BENEFITS	• Share data for evaluation • Document lessons learned	• Share data for evaluation • Document lessons learned	• Monitor and evaluate project performance • Enforce regulation to ensure projects are meeting expectations and benefiting customers

Support from the government, distribution companies, and minigrid developers can promote minigrid awareness, develop pilot projects, and drive scaling of undergrid systems throughout the country.

7. CONCLUSION

Undergrid minigrids present an immediate, practical, and unique opportunity for DisCos, private developers, and communities to work together to achieve a true “win-win-win” for all parties. DisCos can significantly reduce the losses that they currently incur to serve many rural communities, strengthening their ability to address other areas of their business and network. Minigrid developers can access a market with $1 billion in annual revenue potential in Nigeria alone, while using existing distribution infrastructure to reduce capital costs. And communities can reap the benefits of reliable electricity that saves customers money compared with the current mix of infrequent grid power and expensive energy alternatives.

While not without risks, it is worthwhile to explore and experiment with undergrid minigrid opportunities. If a workable arrangement can be found, the near-term and long-term benefits are significant.

APPENDICES

APPENDIX 1. MINIGRID ENVIRONMENT ACROSS SUB-SAHARAN AFRICA

Countries that are most likely to benefit from undergrid minigrid development will feature clear minigrid regulations and low existing grid reliability and/or high power costs.[45]

TABLE 4
MINIGRID ENVIRONMENT ACROSS SUB-SAHARAN AFRICA

COUNTRY	Publicly Available Mg Regulations?	Actual Cost-Reflective Tariffs?	Average End-User Grid Tariff (Cents/Kwh)	System Average Interruption Duration Index (SAIDI) (hrs/y)	Electrification Rate	Population
ANGOLA	No	No	5.4	5	40.5%	29,784,190
BENIN	No	Yes	20.7	-	41.4%	11,175,690
BOTSWANA	No	No	10.5	-	60.7%	2,291,660
BURKINA FASO	No	No	23.3	223	19.2%	19,193,380
BURUNDI	No	No	11.1	660	5.0%	10,864,250
CABO VERDE	No	Yes	25.1	34	92.6%	546,390
CAMEROON	No	Yes	17.1	107	60.1%	24,053,730
CENTRAL AFRICAN REPUBLIC	No	No	10.2	-	14.0%	4,659,080
CHAD	No		23.2	-	8.8%	14,899,990
COMOROS	No	No	27.4	4,240	77.8%	813,910
CONGO, DEM. REP.	No	No	10.9	52	17.1%	81,339,990
CONGO, REP.	No	No	10.6	-	66.6%	5,260,750
COTE D'IVOIRE	No	No	12.0	48	64.3%	24,294,750

TABLE 4 CONTINUED

MINIGRID ENVIRONMENT ACROSS SUB-SAHARAN AFRICA

COUNTRY	Publicly available MG Regulations?	Actual Cost-Reflective Tariffs?	Average end-user grid tariff (cents/kWh)	System Average Interruption Duration Index (SAIDI) (hrs/y)	Electri-fication Rate	Population
EQUATORIAL GUINEA	No	-	23.3	-	67.9%	1,267,690
ERITREA	No	No	23.9	2,470	46.7%	5,918,919
ETHIOPIA	No	No	2.0	-	42.9%	104,957,440
GABON	No	Yes	19.4	34	91.4%	2,025,140
GAMBIA, THE	No	No	21.1	6,031	47.8%	2,100,570
GHANA	No	Yes	24.5	160	79.3%	28,833,630
GUINEA	No	No	20.9	2,658	33.5%	12,717,180
GUINEA-BISSAU	No	-	26.9	-	14.7%	1,861,280
KENYA	No	No	20.2	615	56.0%	49,699,860
LESOTHO	No	No	9.3	-	29.7%	2,233,340
LIBERIA	No	Yes	55.6	68	19.8%	4,731,910
MADAGASCAR	No	No	14.2	-	22.9%	25,570,900
MALAWI	Yes (draft)	No	9.0	-	11.0%	18,622,100
MALI	No	No	13.9	168	35.1%	18,541,980
MAURITANIA	No	No	20.2	21	41.7%	4,420,180
MAURITIUS	No	No	23.1	12	98.8%	1,264,610
MOZAMBIQUE	No	No	9.0	60	24.2%	29,668,830
NAMIBIA	No	Yes	17.0	1	51.8%	2,533,790

TABLE 4 CONTINUED
MINIGRID ENVIRONMENT ACROSS SUB-SAHARAN AFRICA

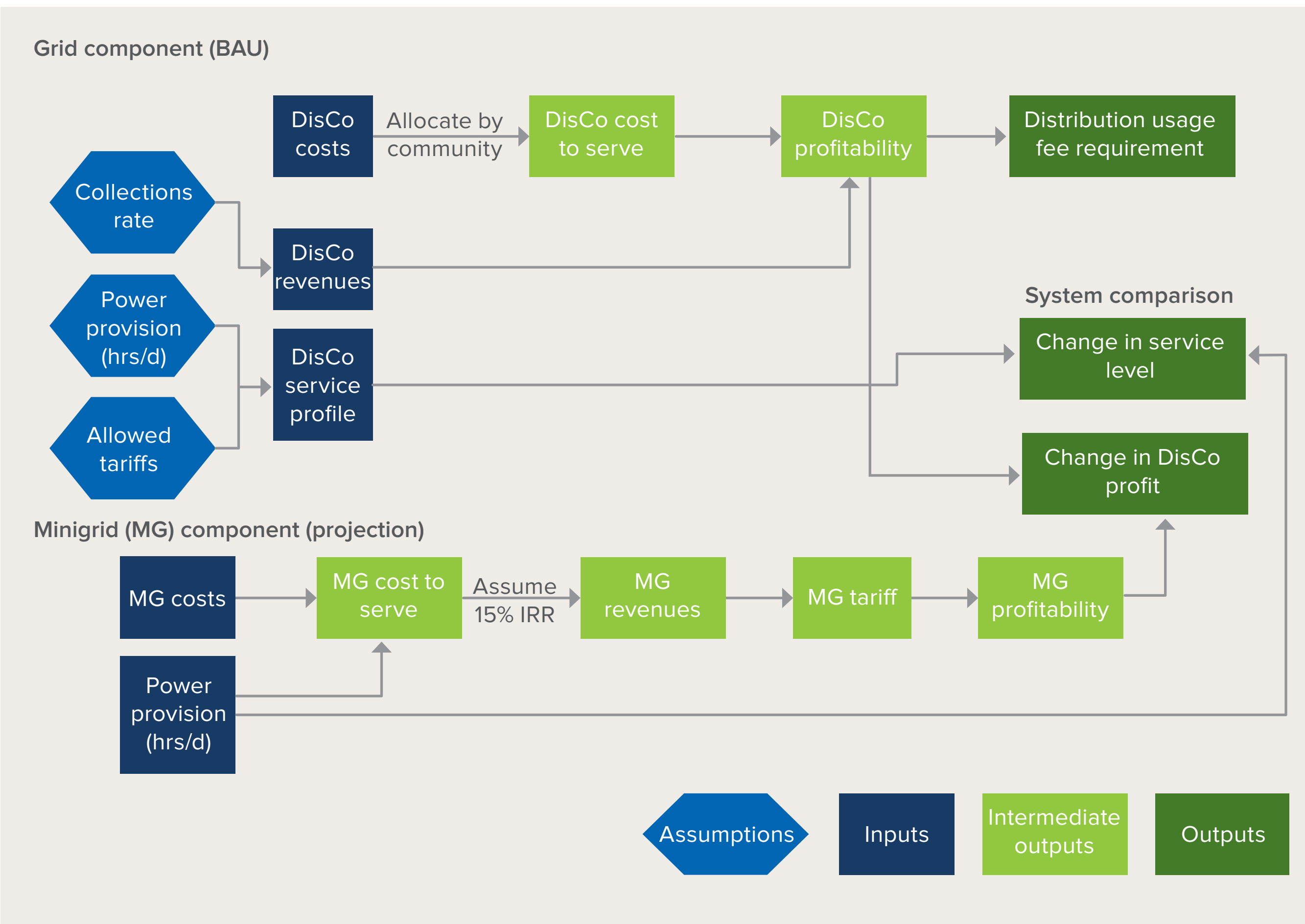
COUNTRY	Publicly available MG Regulations?	Actual Cost-Reflective Tariffs?	Average end-user grid tariff (cents/kWh)	System Average Interruption Duration Index (SAIDI) (hrs/y)	Electrification Rate	Population
NIGER	No		22.1	239	16.2%	21,477,350
NIGERIA	Yes	No	6.5	2,550	59.3%	190,886,310
RWANDA	Yes	No	16.4	-	29.4%	12,208,410
SAO TOME AND PRINCIPE	No	No	17.9	-	65.4%	204,330
SENEGAL	No	No	17.7	95	64.5%	15,850,570
SEYCHELLES	No	Yes	31.0	5	100.0%	95,840
SIERRA LEONE	Yes (draft)	No	24.1	1,830	20.3%	7,557,210
SOMALIA	No		60.0	-	29.9%	14,742,520
SOUTH AFRICA	No	No	11.7	64	84.2%	56,717,160
SOUTH SUDAN	No	No	2.6	1,200	8.9%	12,575,710
SUDAN	No	No	5.4	50	38.5%	40,533,330
SWAZILAND	No	No	10.3	1,391	65.8%	1,367,250
TANZANIA	Yes	Yes	12.0	69	32.8%	57,310,020
TOGO	No		18.4	-	46.9%	7,797,690
UGANDA	No	Yes	16.5	55	26.7%	42,862,960
ZAMBIA	No	No	6.0	82	27.2%	17,094,130
ZIMBABWE	No	Yes	9.9	413	38.1%	16,529,900

APPENDIX 2. UNDERGRID MINIGRID ANALYSIS METHODOLOGY AND ASSUMPTIONS

The minigrid modelling and analysis informing this report compare the profitability of current DisCo service in a remote rural community with the profitability for a minigrid to serve the same community. Profitability is used as a metric since it allows the assessment of company financial health, accounting for both costs and revenues. DisCo finances were assessed through audited financial reports, while minigrid finances are based on best practices and component costs that are available today. Minigrids modelled include PV, battery, and diesel generator components. Customer tariffs ($/kWh) are set based on MYTO restrictions for the grid and the assumption of 15% project IRR for the minigrid. The model, which functions to assess the change in cost, revenue, profit, and service level between the business-as-usual DisCo operations and undergrid minigrid service, is outlined below.

FIGURE 6

MINIGRID MODEL METHODOLOGY



Community assumptions

A single undergrid community was analysed and results extrapolated for a set of undergrid communities within one DisCo franchise area. Based on the number of underserved rural customers and typical community population, the model is based on a community with a population of about 4,500 and a peak load of 250 kW, currently receiving electricity an average of 2 hours per day.

Assumptions for grid performance

The DisCo model is based on data for a single representative DisCo. Collection rates are assumed to be 30% for unmetered and 50% for metered collections in rural areas, based on feedback received from DisCo representatives. DisCo costs are allocated to a single community based on the number of customers or amount of power provided (see **Table 5** below).

TABLE 5

ALLOCATION OF COSTS TO SERVE A SINGLE UNDERGRID COMMUNITY

COST COMPONENT	BASIS FOR ALLOCATION
Power purchase	kWh provided
Billing and collections and customer service	Customers served
Distribution expenses	Customers served
Management and overhead	kWh provided
Asset depreciation — land, buildings, furniture	Assumed to be sunk cost, not allocated
Asset depreciation — distribution assets and vehicles	Customers served
Interest payment	kWh provided
Taxes, license, insurance	kWh provided

Assumptions for minigrid performance

The minigrid model is based on a set of assumptions around component costs today (NESG report; MG 2.0). For the baseline model, the minigrid does not incur any cost of distribution network but bears the cost of customer connections and metering.

Assumptions for market sizing

DisCo losses are calculated based on publicly available audited financial documents, while minigrid profitability is estimated using fixed community size and consumption and targeting 15% project IRR. All market sizing estimates are based on the following assumptions. All market sizing estimates are based on the assumptions shown in **Table 6** on page 35.

TABLE 6
MARKET SIZING ASSUMPTIONS

INPUT ASSUMPTION	VALUE	DATA SOURCE
AVERAGE COMMUNITY POPULATION	4,500	Site visits and RMI analysis
AVERAGE HOUSEHOLD SIZE	4.6	UN[46]
% COMMUNITIES VIABLE FOR UNDERGRID MINIGRIDS	50%	RMI
% HOUSEHOLDS CONNECTED WITHIN COMMUNITY	70%	RMI
COMMERCIAL:RESIDENTIAL CONNECTION RATIO	0.18	MYTO[47]
CONSUMPTION PER RESIDENTIAL CONNECTION	1 kWh/d	ESMAP Multi-Tier Framework[48]
CONSUMPTION PER COMMERCIAL CONNECTION	7.3 kWh/d	MYTO, RMI analysis

ENDNOTES

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