INTERNATIONAL DEVELOPMENT IN FOCUS

Mini Grid Solutions for Underserved Customers

New Insights from Nigeria and India

Bernard Tenenbaum, Chris Greacen,
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1818 H Street NW, Washington, DC 20433
Telephone: 202-473-1000; Internet: www.worldbank.org

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Foreword

Mini grids, powered by solar and batteries, are emerging as a key option in advancing rural electrification for the hundreds of millions of people who do not have access to modern energy. What was once a fringe element of power supply is now coming to the forefront of a new paradigm of distributed energy resources.

The World Bank's Global Facility on Mini Grids has been a pioneer in nurturing the growth of such mini grids. Together with several development partners, we have directed resources and expertise to mobilize private investment in mini grids for isolated villages of Africa and Asia. Such mini grids produce two concrete benefits. First, they can provide first-time access to reliable electricity. Second, they lead to immediate reductions in harmful emissions by reducing the need to run polluting diesel and gasoline generators. Nevertheless, these potential benefits can only be achieved if the mini grid's electricity is affordable *and* can achieve commercial sustainability.

We have seen the recent emergence of a new type of mini grid in low- and middle-income countries: undergrid mini grids. Undergrid mini grids (both interconnected and non-interconnected to the main grid) are being built in communities that are connected to the grid but face poor service supply. In response, firms are beginning to build and operate undergrid solar hybrid mini grids in these countries. In India, more than 600 non-interconnected undergrid mini grids have been built in rural communities. In Nigeria, early examples of undergrid mini grids that are now interconnected have the potential to lower their capital and operating costs through bulk purchases and sales. This, in turn, can make the mini grid's electricity more affordable for its customers and facilitate commercial sustainability.

The key question is whether undergrid mini grids, whether interconnected or non-interconnected, can be scaled up in other countries where the need is great due to grid electricity supply. The answer will depend on whether commercial, technical, and regulatory arrangements can be created for undergrid mini grids that will produce win-win-win economic outcomes for consumers, local Discos, and private mini grid developers. Achieving this will require answers to several important implementation questions:

- What different government and regulatory approaches are available to promote mini grids?

- What business models best support undergrid mini grids interconnected or non-interconnected?
- How can wholesale commercial transactions between mini grid and main grid entities be facilitated?
- What are the incentives and disincentives for existing public and private Discos?
- What are the technical and engineering requirements that must be met for interconnections?
- How can financing be provided projects and what is assistance can donors offer?

Insights from preliminary research on these questions are explored in depth in these pages. The authors offer readers important observations and recommendations on interconnected and non-interconnected undergrid mini grids and their business plans, supporting regulatory frameworks, technical design considerations, and potential benefits. We hope that the early experiences of these projects in Nigeria and India will motivate readers to consider how a more reliable electricity supply from undergrid mini grids could improve the economic and social development of underserved communities.

Demetrios Papathanasiou
Global Director
Energy and Extractives Global Practice
World Bank

Acknowledgments

This book could not have been written without the assistance of many individuals inside and outside the World Bank who gave freely of their time and shared invaluable knowledge and insights on mini grids in both developed and developing countries.

This was especially true of those individuals who assisted us in developing the five case studies in chapter 2. Case studies are usually written one or more years after a project or program has been completed. However, because both interconnected and non-interconnected undergrid mini grids are a relatively new phenomenon in Sub-Saharan Africa and Asia, we found it necessary to prepare case studies on projects and programs that were sometimes in the early stages of development. We were fortunate that our case study informants were open and candid about what was working and what was not working. Equally important, they were willing to share this information in a book that would be made public. So it is with heartfelt appreciation that we acknowledge the advice and assistance of these individuals:

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- **Toto interconnected mini grid** (Nigeria): Kieran Campbell, Aaron Cheng, George Harris, Alastair Smith, and John Ufeoshi
- **Wuse market interconnected mini grid project** (Nigeria): Ifeanyi Orajaka
- **Tata Power Renewable Microgrid initiative** (India): Manoj Gupta and Praveer Sinha
- **Husk Power Systems** (India, Nigeria, and Tanzania): Olu Aruike, William Brent, Brad Mattson, and Manoj Sinha.

The estimates in chapter 4 on cost savings from connecting a mini grid to a main grid would not have been possible without the analysis and insights provided by Muhammad Imran and Oscar Mones from Integration Environment and Energy GmbH. The descriptions of mini grid regulations in Nigeria in chapter 3 benefited from the detailed knowledge of Joanis Holzigel and Nico Peterschmidt of INENSUS GmbH. We are also grateful for the expertise of Sumaya Mahomed in collaborating on the detailed comparison of distribution company (Disco)–mini grid business models in Nigeria and Uganda in appendix B.

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The report was substantively edited by Steven Kennedy, an excellent editor who constantly reminded us that our goal was to communicate information and ideas to a wide audience and to influence real-world outcomes. We are grateful to Mary Fisk and her talented team for transforming the manuscript into a book with gentle but firm guidance.

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About the Authors

Chris Greacen (chrisgreacen@gmail.com) works on policy and hands-on implementation of renewable energy projects from the village to the national level. He helped Thailand develop the region's first regulations supporting grid-connected renewable energy, which now account for over 5,000 megawatts of small grid-connected renewables, and he co-founded the Border Green Energy Team (BGET) on the Thai/Burma border, where he worked with rural communities to build pico-hydropower and solar projects. Since 2008, he has worked primarily as consultant to the Energy Sector Management Assistance Program (ESMAP), developing country programs and regulatory frameworks for renewable energy mini grids in the Caribbean, the Pacific Islands, Southeast Asia, and Sub-Saharan Africa. He is an adjunct professor in the Energy Systems Management program at the University of San Francisco. He holds a BS in physics from Reed College and a PhD in energy and resources from the University of California at Berkeley.

Ashish Shrestha (ashrestha1@worldbank.org) is an energy specialist with ESMAP, where he leads the Integrated Electrification Strategies and Planning program and provides advisory and operational support for mini grid development through the Global Facility on Mini Grids. In his 15 years at the World Bank, he has designed the World Bank's largest investments in mini grids in Ethiopia and Nigeria; coordinated mini grid, biogas, and clean cooking projects in Nepal; and conducted research with the Development Economics Research Group. His current focus is on operationalizing the use of geospatial tools and digital platforms to expedite and improve the preparation and implementation of energy access programs. He holds a BA in economics from Hamilton College and an MA in sustainable international development from Brandeis University.

Bernard Tenenbaum (btenenbaum2002@gmail.com) is an independent energy and regulatory consultant. Before retiring from the World Bank in 2007, he served as a lead advisor on power sector reform and regulation projects in Brazil, China, India, Mozambique, Nigeria, and Tanzania. Before joining the World Bank, he served as the associate director of the Office of Economic Policy at the US Federal Energy Regulatory Commission. He is the author or co-author of *Regulation by Contract: A New Way to Privatize Electricity*

Distribution?; Governance and Regulation of Power Pools and System Operators: An International Comparison; Electrification and Regulation: Principles and a Model Law; From the Bottom Up: How Small Power Producers Can Deliver Electrification and Renewable Energy in Africa; and *A Handbook for Evaluating Infrastructure Regulatory Systems*. Between 2008 and 2013, he was a member of the editorial board of the *International Journal of Regulation and Governance*. From 1966 to 1968, he served as a Peace Corps volunteer in Chile, where he organized consumer and marketing cooperatives. He holds a BA in economics from Colgate University and a PhD in economics from the University of California at Berkeley.

Overview

> "Perhaps up to 2 billion people are fundamentally constrained in their ability to grow because the electricity access they have is erratic and unreliable."
>
> —Dr. Raj Shah, President, Rockefeller Foundation, *Washington Post,* November 16, 2020

INTRODUCTION

Millions of people connected to the main grid in developing countries face unreliable electricity. A 2019 estimate suggested that 2 billion people suffered annual blackouts of 100 hours or more and that 1 billion suffered 1,000 hours or more (IFC 2019). This book explores whether these poorly served customers could benefit from undergrid mini grids.

Undergrid mini grids are mini grids built and operated in a location served by an existing distribution enterprise (commonly referred to as a "Disco") that is connected to the main grid, with which the mini grid may or may not be interconnected. These mini grids could provide valuable services to people living in communities equipped with poles and wires from conventional Discos that are providing inadequate services.

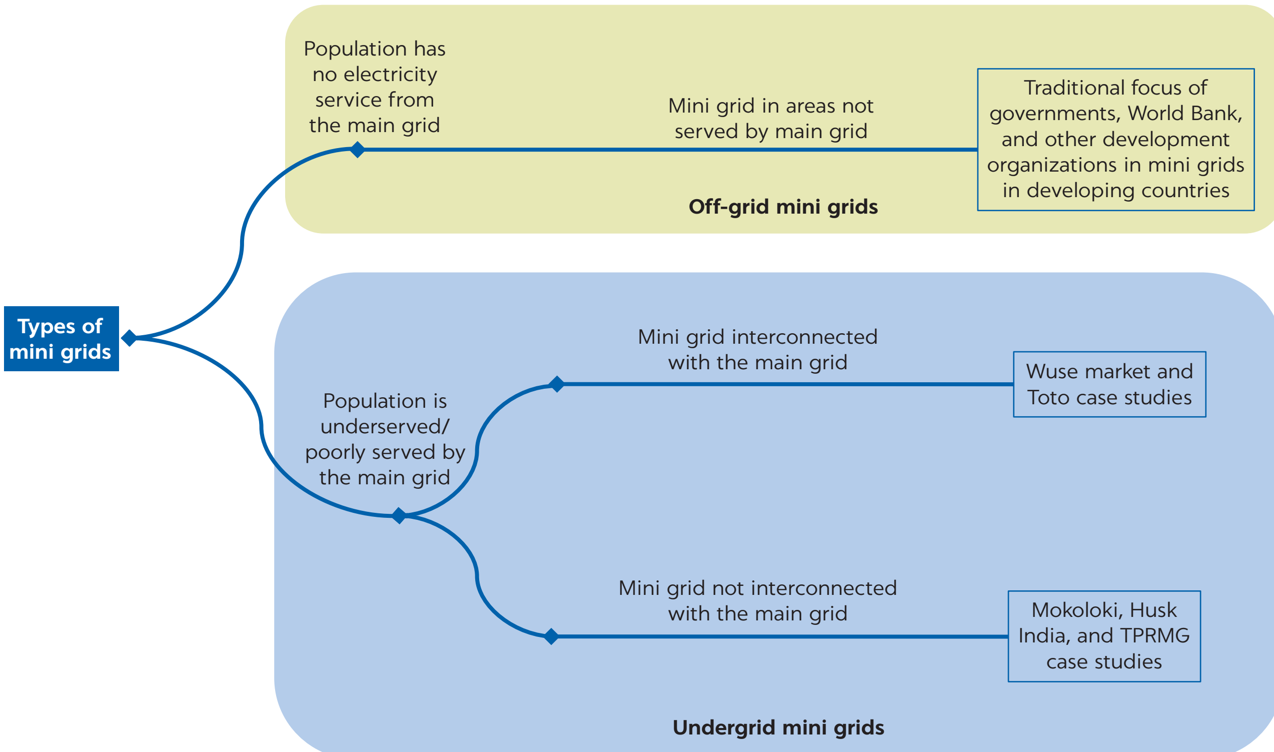
This book also examines weak service in peri-urban areas, which are often poorly served by Discos but are too close to the grid to benefit from government and donor programs that target off-grid areas.

WHAT IS A MINI GRID?

No single definition of mini grids is universally accepted. For the purposes of this book, a *mini grid* will be defined as follows:

> Mini grids are electric power generation and distribution systems that provide electricity to just a few customers in a remote settlement or bring power to hundreds or thousands of customers in a town or city. They can be fully isolated from the main grid or connected to it but able to intentionally isolate ("island") themselves from the grid. Mini grids supply power to households, businesses, public institutions, and anchor clients, such as telecom towers and large agricultural processing facilities. They are designed to provide high-quality, reliable electricity.

FIGURE O.1
Types of mini grids



Source: Original figure created for this publication.
Note: TPRMG = Tata Power Renewable Microgrid.

Traditionally, government and donor efforts to promote mini grids in developing countries have targeted isolated, off-grid areas lacking main grid electricity (refer to figure O.1, top panel). Recently, however, interest has grown in creating undergrid mini grids to supply areas already connected to the main grid but that are receiving poor service (refer to figure O.1, bottom panel).

Undergrid mini grids can be classified as interconnected (mini grids able to buy and, in some cases, sell power to the main grid) and non-interconnected (mini grids relying solely on their own generation despite the presence of power lines from the national utility or local Disco nearby). This book examines the potential for privately owned and operated solar hybrid mini grids, whether interconnected or not, to serve undergrid areas on a commercially viable basis. To ensure that the analysis is grounded in real-world conditions, the book presents five detailed case studies of existing or planned undergrid mini grids in Nigeria and India.

Initially, we considered limiting our analysis to issues specific just to undergrid mini grids. However, it quickly became apparent that an exclusive focus on these issues would ignore the fact that undergrid mini grids are also directly affected by many government and regulatory decisions that apply to all mini grids. For this reason, where appropriate, the book also examines issues that pertain to all mini grids.

THE NEED FOR TRIPLE WINS—FOR MINI GRID RETAIL CUSTOMERS, DISCOS, AND MINI GRID DEVELOPERS

Interconnected mini grids are likely to come into existence and be sustainable only if they can create a win-win-win outcome for retail customers, Discos, and mini grid developers. For customers, the mini grid must be able to provide affordable electricity that is more reliable and of better quality than the electricity they already receive. For the Disco, it must be clear that signing an agreement with an interconnected mini grid will increase its bottom line—by cutting financial losses, leasing its distribution network, and wholesaling electricity to the mini grid. For the mini grid company, it must be clear that the agreement (supported by credible government policy and regulatory decisions) will lead to a commercially viable interconnected mini grid with lower costs than a non-interconnected mini grid.

Benefits for retail customers

Mini grids almost always provide their customers with a more reliable source of energy than that provided by the Disco. In the absence of reliable grid electricity, customers are forced to operate their own backup electricity generation with expensive, noisy, and polluting diesel generators or to use candles or kerosene lamps for light. Before mini grids were installed, customers in the Wuse market in Abuja, Nigeria, relied on backup petrol generators for about half of their electricity. Thanks to mini grid uptimes exceeding 99 percent for the small section of the market currently served by the mini grid operator Green Village Electricity (GVE), the customers no longer need this backup. Mini grid customers in the Wuse market now pay about 65 percent less for energy services than they used to pay.[1] Receiving electricity from a local mini grid may also improve the accuracy of billing, the response time for complaints, and the reliability and quality (voltage and frequency) of the electricity provided.

Benefits for the Disco

One determinant of whether connecting to a mini grid benefits a Disco is whether it had been serving the community at a profit or a loss. In a 2018 report, the Rocky Mountain Institute (RMI) estimated that a typical Nigerian Disco with 4,500 rural customers lost an average of US$0.21 per kilowatt-hour (kWh) (RMI 2018). In such circumstances, handing off money-losing customers to mini grids can be an attractive proposition to a Disco.

A second factor is the revenue the Disco may receive by leasing out its distribution grid. Mini grids in Nigeria's Interconnected Mini-grid Acceleration Scheme (IMAS) are expected to pay a so-called Distribution Use of System (DUOS) charge of US$0.006–US$0.013 per kWh sold at the retail level.

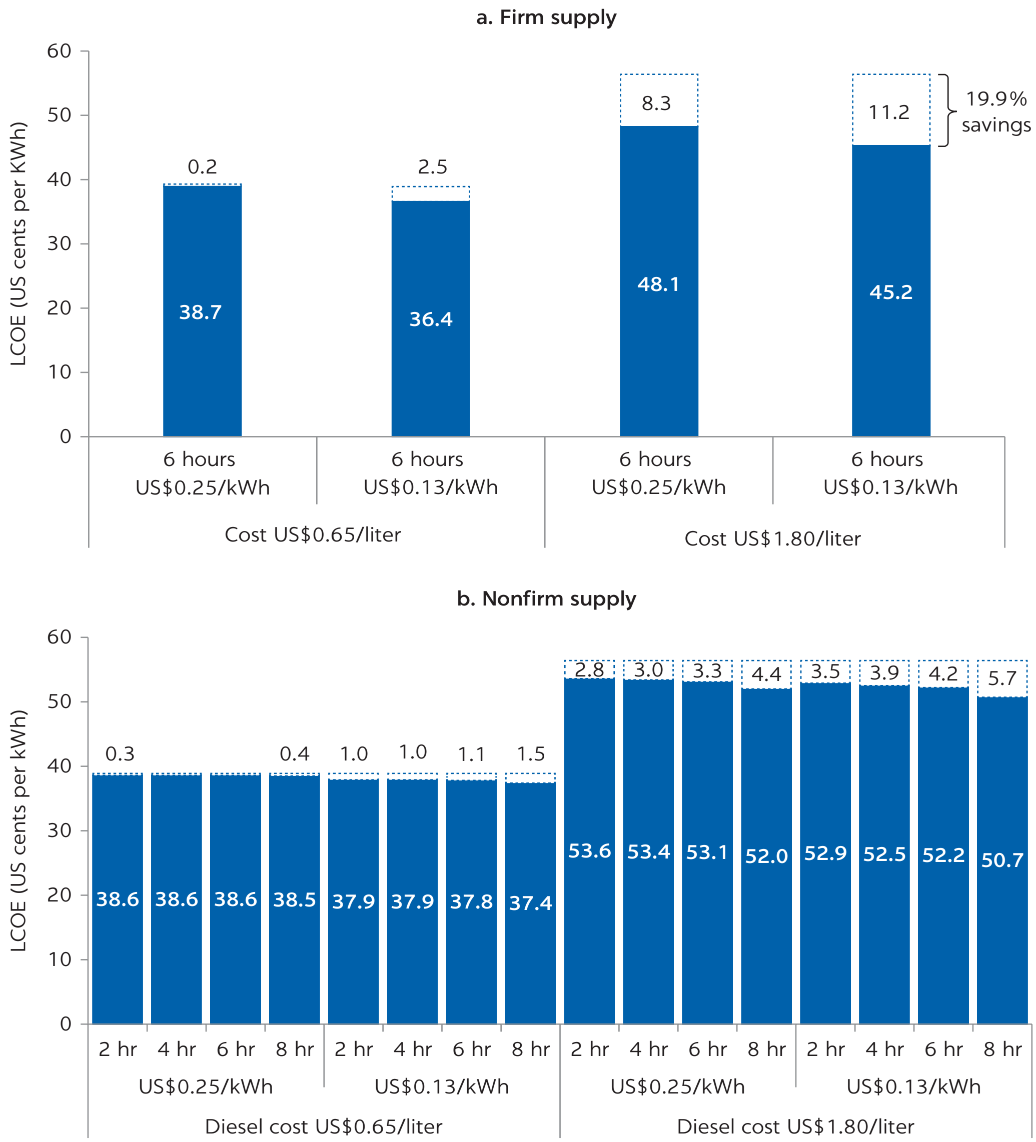
Discos can also potentially earn revenues from bulk sales of electricity to interconnected mini grids. In Nigeria's IMAS, bulk supply tariffs are US$0.067–US$0.135/kWh for nonfirm supply, whereas the Wuse mini grid pays US$0.11–US$0.17/kWh for firm power. The Abuja Electricity Distribution Company (AEDC), which previously served the Wuse market, estimated that its total revenues will increase by 70 percent once it becomes a wholesale supplier to the mini grid.

Benefits for the mini grid operator

Connecting to a main grid can bring benefits to the mini grid operator in the form of lower operating costs and capital costs. Mini grids can lower operating costs if the price they pay for electricity purchased from the local Disco is lower than the cost of supplying the same amount of electricity themselves. This is likely to be true for electricity that would be generated by mini grids during nonsunny hours, when the electricity must either be drawn from a battery or generated by a diesel generator. Capital costs can be lowered if the purchase of electricity from the Disco allows the mini grid to reduce its overall investment in equipment such as batteries, solar panels, and diesel generators. Savings vary widely depending on the price of diesel fuel, the price of electricity purchased from the Disco, the number of hours of Disco electricity supply, and the timing of supply. Assuming a diesel fuel cost of US$1.80 per liter, a duration of 6 hours, and a wholesale tariff of US$0.13/kWH, a mini grid with a firm supply agreement with a Disco can reduce its levelized cost of electricity by almost 20 percent, as compared with a project that is not connected to the main grid (figure O.2, panel a). Savings from interconnecting with a nonfirm supply are about 50 percent lower (figure O.2, panel b).

FIGURE O.2

Levelized cost of electricity of a hypothetical mini grid connecting to a Disco



Source: Original figure created for this publication using data supplied by the Interconnected Mini-grid Acceleration Scheme (IMAS).
Note: Panel a assumes 6 hours of evening firm supply of electricity. Disco = distribution company; kWh = kilowatt-hour; LCOE = levelized cost of electricity.

Another potential interconnection benefit for mini grids would be revenues earned from electricity sales to the Disco. This type of sale has not yet occurred in the five case studies presented in chapter 2.

POLICY AND REGULATORY ISSUES FOR UNDERGRID MINI GRIDS

Several commercial elements could potentially be regulated, affecting the financial sustainability of undergrid mini grids (refer to table O.1).

In Nigeria, the commercial elements that are unique to interconnected mini grids (shown in bold in table O.1) are set out in tripartite agreements among the mini grid operator, the Disco, and the community and are subject to approval by the national electricity regulator, the Nigerian Electricity Regulatory Commission. The Commission has issued general templates for tripartite agreements, which can be adjusted by the parties to the agreement to suit their specific circumstances, subject to the Commission's approval. By contrast, in India, non-interconnected undergrid mini grids in rural areas are not required to obtain licenses or approval of their tariffs from the national or state regulators, making them effectively deregulated. At present, it is unclear how these non-interconnected mini grids in India would be regulated if they were to interconnect to the local Disco.

A regulatory approach that involves a separate review of each major element of bilateral or tripartite agreements could be complex and time consuming. Changes mandated by the regulator to one or more elements of a negotiated agreement could affect the balance of interests within the agreement and could cause the Disco or mini grid developer to walk away from the agreement. A light-handed regulatory approach that lets Discos and mini grid developers arrive at their own commercial arrangements for individual contractual elements would generally be preferable. Rather than separately judging each and every element of the interconnection agreement on a stand-alone basis, the regulator's decision to approve or disapprove would be based on the answers to two questions: Will the interconnection agreement lead to lower end-use tariffs for retail customers? Will technical and safety requirements be met?

TABLE O.1 Commercial elements of undergrid mini grids that could potentially be regulated

	TYPE OF UNDERGRID MINI GRID	
ISSUE	*INTERCONNECTED*	*NON-INTERCONNECTED*
Licensing/permitting	✓	✓
Tariffs for retail sales	✓	✓
Recovery of costs to promote productive and household uses of electricity	✓	✓
Compensation when the main grid arrives	n.a.	✓
Length of the agreement	✓	✓
Tariffs for bulk purchases by the mini grid	✓	n.a.
Tariffs for bulk sales by the mini grid	✓	n.a.
Leasing of an existing distribution system	✓	Sometimes
Compensation for energy not supplied by the Disco	✓	n.a.
Compensation if the Disco takes back a subconcession	✓	Sometimes

Source: Original table for this publication.
Note: Elements unique to interconnected mini grids are shown in bold. Disco = distribution company; n.a. = not applicable.

Improving the incentive structure for Discos

The current cost-of-service regulatory system widely used in India and Sub-Saharan Africa may discourage Discos from collaborating with interconnected mini grids, because Discos earn profits based on their asset base, as defined by the regulators. If a mini grid operator succeeds in creating a profitable mini grid, a Disco will have a strong incentive to take over the mini grid's assets to boost its regulatory asset base, earn higher profits, and eliminate a retail competitor. Integrating performance-based elements into cost-of-service regulation, as the United Kingdom and the United States have done, could encourage collaboration with rather than opposition to mini grids.

Performance-based regulation could be an especially useful alternative in Nigeria and India, where Discos have problems accessing upstream generation supply. Mini grids and other distributed energy resources could offer a new downstream supply source. Nigeria's regulatory mandate that Discos procure 10 percent of their power from distributed sources by 2024 could be reinforced by a performance-based system, which would incentivize Discos to collaborate with mini grids and other distributed energy resources.

Technical design for interconnection

The emerging generation of solar mini grids benefits from the ability to interconnect with the national grid to lower customer costs while providing high levels of reliability and resilience to natural disasters. However, connecting mini grids to the national grid raises six key technical questions:

1. Will the mini grid's distribution network—but not its generation and storage systems—connect to utility power?
2. Will the national grid ever be used to charge the mini grid's batteries in addition to supplying customers' loads?
3. Can electricity flow from the mini grid back to the national grid?
4. How will "islanding" (the operation of the mini grid's generation and distribution system in electrical isolation from the main grid) and reconnection be accomplished?
5. Can mini grid inverters provide ancillary (grid support) services to the main grid?
6. Is the distribution network of the mini grid built to safely interface with the main grid power?

CASE STUDIES

Our research is grounded in five detailed case studies (chapter 2) of interconnected and non-interconnected mini grids in undergrid areas in Nigeria and India. The case studies were developed through more than 50 interviews with developers, Disco executives, consultants, and government officials. We focused on private sector–led development of mini grid sites, with regulation and without it, because these are currently the dominant approaches in three large countries (India, Nigeria, and Tanzania) in Africa and Asia. The developments in these three countries provide substantial and growing on-the-ground experience that can be observed and evaluated. The five case studies cover existing or proposed undergrid mini grids. Two (Toto and Wuse in Nigeria) are interconnected; three (Mokoloki in Nigeria and Tata and Husk in India) are currently non-interconnected.

The Mokoloki mini grid (Ogun state, Nigeria) is an electrically isolated undergrid mini grid with 100-kilowatt-peak (kWp) solar photo voltaic (PV), 317 kWh battery storage, and an 88-kilowatt (kW) backup diesel generator. Its developer, Nayo Tropical Technology, is leasing the existing distribution facilities of the Ibadan Electricity Distribution Company. The mini grid began operations in February 2020. The principal contractual document is a tripartite agreement among the local Disco, the local community, and the mini grid developer. At some point in 2024, the mini grid hopes to become interconnected to the Disco in order to make bulk purchases from it. Negotiations have been delayed because the Disco is now in receivership and has a new management team.

The Toto mini grid (Nasawara state, Nigeria) is an operating interconnected mini grid in the licensed service area of the AEDC with 352 kWp solar PV, 972 kWh battery storage, and a 500-kilovolt-ampere backup diesel generator. Its developer, PowerGen, expects to receive 6 hours of evening electricity daily from AEDC, which will allow it to serve about 2,000 residential and commercial customers. PowerGen is investing about US$500,000 of the total planned investment of US$2 million to rehabilitate and expand AEDC's existing distribution grid to be able to serve a customer base that is expected to grow during the mini grid's 20-year permit period.

The Wuse market mini grid (Abuja Federal Capital Territory, Nigeria) is an interconnected mini grid built to serve owners of shops and stalls in a large urban market. The mini grid has 1-megawatt-peak solar PV, 1.2-megawatt-hour battery storage, and a 1-megawatt backup diesel generator. As part of its Energizing Economies program, Nigeria's Rural Electrification Agency conducted energy audits of the market and helped select the mini grid developer and operator GVE. The pilot phase is under way; when the project becomes fully operational, it is expected to replace the more than 3,000 small diesel generators operated by the market's merchants. During the 20-year term of the tripartite agreement between AEDC, GVE, and the Wuse Market Shop Owners Association, GVE will be the designated supplier to all shops and stalls. GVE has a firm commitment from AEDC to sell GVE 7 hours of electricity each night. An estimated 300 other urban marketplaces could be served by similar interconnected mini grids elsewhere in Nigeria.

Tata Power Renewable Microgrid (TPRMG, India). In November 2019, Tata Power, India's largest power company, announced an initiative to create 10,000 microgrids in towns and villages already served by main grid–connected Discos that are typically government-owned. Using a standard generation package that includes a 30 kWp solar array, lead acid batteries with 30 kWh of usable energy storage, and a 25-kilovolt-ampere diesel generator that can be deployed in multiple units for larger sites, Tata provides service that is considerably more reliable than that of the local Discos. To increase customer demand, Tata helps customers obtain financing for appliances and productive machinery. By the end of June 2023, Tata had installed and was operating 200 mini grids, and it is exploring using biogas generators to replace more expensive diesel-fired generation and battery storage. To date, all of TPRMG's financing comes from Tata Power, its parent company.

Husk Power Systems (India and Nigeria). Husk operates 200 non-interconnected mini grids serving more than 5,000 microenterprises in India and Nigeria using a standard modular supply system consisting of a 50 kWp of PV array, lead-acid batteries, and a biomass gasifier. The company's mini grids in India are non-interconnected, undergrid projects. Most of Husk's customers are served on a prepaid basis. In November 2021, Husk began operations at six non-interconnected mini grids in Nigeria's Nasarawa state. In 2024, the company expects to reach an agreement with one of Nigeria's Discos to operate at least two interconnected mini grids. In October 2023, Husk announced that it had attracted US$103 million in equity and debt financing, which should allow it to greatly scale up its operations in both Africa and India. The sum would represent the largest single quantity of external financing ever obtained by a mini grid company using Husk's bottom-up approach.

KEY OBSERVATIONS AND RECOMMENDATIONS

Based on the five case studies in this study book and our experience working with mini grid programs in more than 20 low- and middle-income countries, we offer observations and recommendations that are summarized later and detailed in chapters 6 and 7. Some are specific to undergrid mini grids, and others apply to mini grids in general. (Because undergrid mini grids are one type of mini grid, they will be affected by government policies and regulations that apply to all mini grids.)

Observations

The costing models currently used for least-cost planning of rural electrification usually conclude that grid densification and line extension to nearby areas are the most cost-effective ways to expand access to electricity. The weakness of these current economic and engineering models is that they assume that all Discos will be motivated and efficient operators. Under the standard models currently used by governments and donors, Discos will always be the recommended choice for grid densification and line extension to nearby areas. In fact, in most of these cases, the least-cost planning models do not project any role at all for undergrid mini grids. However, our findings suggest that privately owned and operated undergrid mini grids can often provide a more cost-effective and usually more reliable alternative for consumers in communities where the reliability and operational performance of national and local grids are poor.

Incentives matter! Discos and mini grid operators have different incentives to increase rural sales. A Disco manager may have been ordered by a ministry to connect new communities. However, if the Disco is limited to charging non-cost-recovering tariffs (which is the norm in many developing countries), a rational manager will privately express the concern, "Why should I encourage my staff to increase sales in rural areas if I know that I will lose money on almost every additional kilowatt-hour I sell in these villages?" In contrast, a manager of a privately owned mini grid will say, "As a privately owned company, I may get an initial capital grant, but I don't have the cushion of continuing government subsidies after I start operations. So, unless I increase sales to achieve profitability, I won't survive." The effects of differing incentives can be readily observed in the real-world behavior of Discos and mini grids. It appears that most new third-generation mini grid developers in Nigeria and India have active, on-the-ground programs to increase the electricity consumption of their commercial and residential customers. In contrast, very few Discos have similar programs to increase consumption.

Interconnected mini grids can serve different target markets. Target markets for interconnected mini grids include rural and peri-urban towns and villages, large urban market centers with intermittent electricity supply, commercial and industrial (C&I) installations, and universities and hospitals. The focus in this book is on privately owned and operated undergrid mini grids serving rural and peri-urban towns and villages and large market centers. A key open question is whether interconnected mini grids can be a win-win solution for C&I customers and the Discos in whose service areas the C&I customers are located.

Interconnection can reduce the levelized cost of electricity (LCOE) of a mini grid, as well as its capital and operating expenses. A cost analysis of six proposed interconnected mini grids in Nigeria projects that the lower operating and capital expenses of the interconnected mini grids can yield LCOE savings of up to 20 percent as compared with a non-interconnected mini grid. The actual savings will depend on the cost of wholesale electricity from the Disco, the cost of diesel fuel, the hours per day that the Disco can provide electricity, and whether the Disco is willing to be contractually obligated to provide firm electricity at the same time every day. A firm electricity supply contract can roughly double the LCOE savings as compared with a nonfirm wholesale supply arrangement.

Discos may be unable to supply firm power to interconnected mini grids. First, interconnecting and guaranteeing a steady supply of electricity may require significant financial investment by Discos. Discos may not have the money to make these investments, or they may have concluded that their limited investment funds are better used for other purposes (for example, installing meters for their nonmetered customers). Second, the reliability of the Disco's electricity supply may depend on upstream generation and transmission that the Disco cannot control. A manager may have to tell a mini grid developer, "We can't supply you with firm power because we don't have it. It would be too risky for me to give you a firm supply commitment when I can't be sure that I will have the supply!"

Some mini grid companies are already achieving cost reductions from economies of scale and standardization. In India, developers like Husk and TPRMG have accomplished this by grouping small, standardized mini grid projects located near each other. Also, data from the African Minigrid Developers Association (AMDA) show that established mini grid companies tend to have lower average costs than newer ones. This difference has also been observed in India. Husk has reported LCOEs of less than US$0.30/kWh at its newer sites in India and has set a target of US$0.17/kWh by 2030. With these cost reductions, Husk reported in January 2023 that it had achieved operating cost profitability in Nigeria and India, an intermediate milestone to full cost recovery.

Privately owned and operated mini grids will not scale up to any significant degree unless they can obtain commercial financing (both debt and equity). Commercial financing requires that a mini grid enterprise be profitable. To date, most financing for private mini grids has come from donors and development finance institutions (DFIs). The financing is typically provided for individual projects or groups of projects. Although donor and DFI financing may be adequate for pilots, it is not a workable option for a full scale-up of mini grids. The problem with relying on donor and DFI funding for full scale-up is that they may not have enough money and the money may not be available when needed. If mini grids are to achieve their full potential, their financing will have to shift from project financing to enterprise/company financing and from donors and DFIs to commercial lenders and investors. Commercial/private financing will be forthcoming only if mini grid enterprises can demonstrate full profitability—that is, full recovery of operating and capital costs.

In Nigeria and India, evidence from the case studies suggests that mini grids perform certain functions better than utilities. Mini grids generally excel in (1) accurately metering usage and collecting payments from customers, (2) providing a reliable supply of electricity with fewer harmful variations in voltage and frequency, and (3) increasing growth in customer demand through financing options for appliances and machinery.

Mini grid operators of community-based mini grids who make no effort to increase customer loads will almost certainly fail. Successful mini grid operators have learned that they need to do two things: (1) reliably provide electricity with good voltage and frequency attributes and (2) increase customer loads so that the mini grid earns enough revenue to stay in business. Accordingly, the ability to survive over the long run requires both technical and marketing competence. To paraphrase one mini grid operator, "In the communities we serve, we quickly realized that we are in the business of producing good quality electricity and also promoting load growth by financing machines and appliances for our customers. You need to do both, or you will fail." Anecdotal evidence (refer to the Husk and TPRMG case studies in chapter 2) shows that the more successful mini grid companies devote considerable time and resources to increasing customer loads and the mini grid's revenues. In fact, Husk Power, which has built and is operating 200 mini grids in Nigeria and India, has gone beyond simply financing "productive uses" of electricity by its customers. It provides education, training, and business development for customers who operate micro and small enterprises. Husk is also experimenting with forming and operating its own enterprises powered by electricity.

A detailed mini grid tariff review for each project will impede rapid scale-up. If a government aims to escalate private-led investment in mini grids, such as the Nigerian government's objective of 10,000 mini grids, traditional regulatory processes and tariff-setting methods could easily become barriers to scale-up. To achieve the government's goal, the regulator must streamline the processes of obtaining licenses and permits and setting tariffs while continuing to protect mini grid customers.

A government program that supports a bottom-up, private developer–led approach may not be feasible in all countries. Our five case studies were limited to the bottom-up, private developer–led approach implemented in Nigeria and India. This approach has had some success. In three Indian states (Bihar, Jharkhand, and Uttar Pradesh), more than 600 mini grids have come into existence over the past several years, with 19 megawatts of installed capacity, and the growth rate in mini grids seems to be accelerating. In Nigeria, with the benefit of a US$600 per connection grant, 110 mini grids are now operating, and another 65 are actively under construction (as of October 2023). However, for at least two reasons, it would be naïve to conclude that this bottom-up model will be readily transferable to other countries. First, it requires a baseline level of good governance and the presence of domestic entrepreneurs with experience in the electricity sector. Without these, governments may have to rely on experienced foreign firms backed by long-term concession contracts rather than by regulatory licenses or permits. Second, attracting investment from private developers may not be viable if the national or regional utility has already achieved high levels of electrification or is opposed to allowing new independent retail suppliers of electricity. Top-down government-led approaches may be more workable in these countries, at least initially.

Recommendations

Interconnected mini grids should be voluntary. Interconnected mini grids must produce a win-win-win outcome for end-use customers, Discos, and the mini grids themselves. Discos should not be forced to interconnect with mini grids. They need to be assured that interconnecting will be commercially beneficial and enable them to serve their customers better, compared with other alternatives. If a Disco is unconvinced that an interconnection with a mini grid will benefit itself and its customers, it can easily undermine any policy or regulatory mandate to interconnect in subtle ways that are difficult to detect.

To effectively regulate both interconnected and non-interconnected mini grids, regulators should consider making several regulatory changes:

- Move away from setting tariffs based on cost-of-service reviews for individual projects.
- If tariffs are regulated, implement automatic tariff adjustments to account for cost changes, such as inflation and currency fluctuations, that are beyond the mini grid operator's control.
- Encourage mini grid operators to provide customers with tariffs based on time of use and contracted reliability levels.
- Issue blanket licenses and permits for portfolios of mini grid projects with similar characteristics.
- Grant long-term licenses or permits to support project financing, and clearly define criteria and procedures for license transfers.
- Ensure that regulatory frameworks include basic safety requirements for all mini grids, as well as a checklist of minimum technical and operating protocols for interconnected mini grids. The specific details of the technical and operating protocols for individual projects should be determined by the mini grid operator and the Disco. The regulator can assist by providing a list of the elements that would normally be included in such an agreement.

Regulators should consider new regulatory frameworks to incentivize Discos to interconnect to mini grids. Integrating aspects of performance-based regulation, as seen in countries like the United Kingdom and the United States, could encourage Discos to collaborate with, rather than oppose, mini grids.

Regulators should focus on the final retail price charged to the customers of interconnected mini grids. We recommend a light-handed approach that lets Discos and mini grid developers arrive at their own commercial arrangements, as long as these arrangements lead to lower end-use tariffs for customers and satisfy technical and safety requirements.

Government and donors should provide technical assistance to both mini grid developers and Discos to negotiate technical and commercial agreements for potential interconnected mini grid projects. To date, most donor technical assistance has gone to mini grid developers. However, Discos also need support, because they often lack experience in negotiating with nonaffiliated electricity suppliers and may not understand the financial and technical benefits that interconnection can bring to their operations. Therefore, technical and economic consultants should act as neutral facilitators between Discos and mini grid developers during negotiations for interconnection agreements.

Governments and donors should support interconnected mini grid pilots in other market segments. The five case studies in this book focus on mini grids in rural and peri-urban communities and large urban marketplaces. However, interconnected mini grids and other distributed energy options should also be considered for C&I installations, public institutions such as universities and hospitals, and urban residential communities. Additionally, the technical and commercial viability of downstream interconnections between mini grids and meshed direct current grids serving the poorer fringes of communities should be evaluated in pilot projects.

Follow-ups to the case studies should be performed to learn whether the undergrid mini grids studied in this book have achieved commercial feasibility. It would be beneficial to perform status updates on the Mokoloki, Toto, and Wuse interconnected mini grids after they have been in operation for at least a year. Doing so would provide insights into their long-term performance and success. We also recommend studying a sample of the proposed interconnected mini grids supported by IMAS in Nigeria—both those that were successful and those that were not.

Case studies should be performed on interconnected mini grids in other market segments beyond the rural and peri-urban towns and large urban market centers that are the focus of this book. These additional case studies would include interconnected distributed energy resources for C&I customers, public institutions (for example, universities and hospitals), and urban residential communities. Downstream interconnections between mini grids and meshed direct current grids should also be examined. These additional case studies should cover commercial transactions and contractual agreements with the main grid, benefits and costs for both the main and mini grid, financing methods, ownership, regulation, and technical design and operation.

NOTE

1. This figure was calculated before the removal of the fuel subsidy in Nigeria, which went into effect on May 31, 2023. With the drastically increased price of petroleum products, the savings to end users from switching to mini grid electricity are now probably even higher.

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Abbreviations

24/7	24 hours a day, 7 days a week
AC	alternating current
AEDC	Abuja Electricity Distribution Company
AFD	Agence Française de Développement
AFUR	African Forum of Utility Regulators
AMADER	Agence Malienne pour l'Energie Domestique et de l'Electrification Rurale
AMDA	African Minigrid Developers Association
ARPU	average revenue per user
BBPS	Bharat Bill Payment System
C&I	commercial and industrial
CAPEX	capital expenses (or expenditures)
CBN	Central Bank of Nigeria
CO_2	carbon dioxide
DC	direct current
DER	distributed energy resource
DESSA	Distributed Energy Solutions Strategy (for AEDC)
DFI	development finance institution
Disco	distribution company
DUOS	Distribution Use of System
EAP	East African Power
EBITDA	earnings before interest, taxes, depreciation, and amortization
EEU	Ethiopian Electric Utility
EP	Equatorial Power
ERA	Electricity Regulatory Authority
ESMAP	Energy Sector Management Assistance Program
EWURA	Energy and Water Utilities Regulatory Authority
FPC	Federal Power Commission (US)
GIZ	German Agency for International Cooperation
GVE	Green Village Electricity
HOMER Pro	Hybrid Optimization of Multiple Electric Renewables
Hz	hertz

IBEDC	Ibadan Electricity Distribution Company
IFC	International Finance Corporation
IMAS	Interconnected Mini-grid Acceleration Scheme
KPLC	Kenya Power and Lighting Company
kV	kilovolt
kVA	kilovolt-ampere
kW	kilowatt
kWh	kilowatt-hour
kWp	kilowatt-peak
LCOE	levelized cost of electricity
LCOS	levelized cost of energy storage
LED	light-emitting diode
Li-ion	lithium-ion
MAS	Mini-grid Acceleration Scheme
MIB	microgrid in a box
MIGA	Multilateral Investment Guarantee Agency
MSMEs	micro, small, and medium enterprises
MW	megawatt
MWh	megawatt-hour
MWp	megawatt-peak
MYTO	multiyear tariff order
NEP	Nigeria Electrification Project
NERC	Nigerian Electricity Regulatory Commission
NESP	Nigerian Energy Support Programme
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
OPEX	operating expenses (or expenditures)
PBG	performance-based grant
PHARES	Programme Haïtien d'Accès des communautés Rurales à l'Energie Solaire (Haitian Program for Access to Solar Energy in Rural communities)
PPA	power purchase agreement
PV	photovoltaic
QAF	Quality Assurance Framework
REA	Rural Electrification Agency
RMI	Rocky Mountain Institute
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SDG	Sustainable Development Goal
SERC	State Electricity Regulatory Commission (India)
SMA	System, Mess and Anlagentechnik
SPV	special purpose vehicle
SUNREF	Sustainable Use of Natural Resources and Energy Finance
TPRMG	Tata Power Renewable Microgrid
V	volt
W	watt
Wp	watt-peak
WP	Work Program (in Sierra Leone)
WUMATA	Wuse Market Traders Association

Introduction

"Not everything that is faced can be changed, but nothing can be changed until it is faced."

—James Baldwin, American writer, 1962

"The current is too high or too low, never quite right. A wire has melted. Another compressor will need to be replaced."

—Chimamanda Ngozi Adichie, Nigerian author, *New York Times,* January 31, 2015

THE PROBLEM OF POOR ELECTRICAL SERVICE

In 2015, the United Nations approved 17 Sustainable Development Goals (SDGs). Of these, SDG 7 commits the world to achieving universal electrification by 2030. Significant progress has been made toward meeting this goal. In 2010, more than 1.2 billion people lived without electricity. That number dropped in 2016 to 849 million and in 2020 to 768 million, 568 million of whom lived in Sub-Saharan Africa (IEA and others 2022).

Access to electricity has risen. However, access statistics are based on electrical connections, not on the quality of service.[1] No matter how poor service is, a customer with a connection is classified as "electrified."[2] These figures therefore give an incomplete picture of the level of electrification.

Poor service is a serious problem in Nigeria. Photos I.1 and I.2 show typical scenes in the Wuse marketplace in Abuja, the federal capital of Nigeria, and outside a maize-milling shop in the nearby community of Waru. Because of the unreliability of the electrical service provided by the local distribution company (Disco), store owners install small backup diesel and petrol generators or wait for the electricity to come back on. The estimated installed capacity of Nigeria's 22 million small backup generators is an astonishing 42 gigawatts—about eight times the installed peak generating capacity of the main grid (A2EI 2019). About 78 percent of main grid customers in Nigeria report that the grid "works about half the time, occasionally, or never" (Chingwete, Felton, and Logan 2019).[3] When the grid does not work, the

PHOTO I.1

Small diesel generators at the Wuse market in Abuja, Nigeria, 2019

Source: © Arne Jacobson, Schatz Energy Research Center, California State Polytechnic University, Humboldt (Cal Poly Humboldt). Used with permission; further permission required for reuse.
Note: Shopkeepers at the Wuse market run hundreds of individual small diesel or gasoline generators, one for each storefront. Shopkeepers in one section of the market are currently served by the mini grid. It is expected that those in the rest of the market will be served by the mini grid before the end of 2023, which will alleviate or eliminate reliability problems.

backup generator "fills the air with smoke, ear-splitting noise, and climate change fueling pollution" (Rowling 2022).

The problem of unreliable supply for connected customers is not limited to Nigeria. A 2020 article in *Electricity Journal* (Ayaburi and others 2020) measures the reliability of service in 179 countries using two self-reported standard industry measures of annual reliability: the frequency of outages (the System Average Interruption Frequency Index [SAIFI]) and the duration of outages (System Average Interruption Duration Index [SAIDI]).[4] The authors define "reasonable reliability" as having a SAIFI of fewer than 12 outages per year and a SAIDI of less than 12 hours per year.[5] Based on these two measures, they find that about 3.5 billion people (about half the world's current population) lack access to reliable electricity. Even if one uses a more forgiving threshold of 24 rather than 12 hours without electricity, more than 1.6 billion people lack reliable electricity. Both 3.5 billion and 1.6 billion are much larger numbers than the estimated 789 million people in 2018 who did not have a physical connection to any electricity. Using different data, the International Finance Corporation (IFC) calculates that, in 2016, 2 billion people worldwide experienced annual blackouts of 100 hours or more and 1 billion experienced annual blackouts of 1,000 hours or more (IFC 2019).[6]

PHOTO I.2

Unreliable Disco power means uncertainty and wasted time in maize milling in Waru, Nigeria

Source: © James Sherwood, Rocky Mountain Institute. Used with permission; further permission required for reuse.
Note: Disco = distribution company.

Nigerian author Chimamanda Ngozi Adichie (2015) vividly describes the human cost of unreliable and poor-quality electricity:

> I cannot help but wonder how many medical catastrophes have occurred in public hospitals because of "no light," how much agricultural produce has gone to waste, how many students forced to study in stuffy, hot air have failed exams, how many small businesses have foundered. What greatness have we lost, what brilliance stillborn? I wonder, too, how differently our national character might have been shaped, had we been a nation with children who took light for granted, instead of a nation whose toddlers learn to squeal with pleasure at the infrequent lighting of a bulb.

THE PURPOSE AND ORGANIZATION OF THIS BOOK

This book examines how the reliability and quality of electricity service can be improved for people who already have a physical connection to the main electricity grid. It examines whether mini grids, interconnected or not, can help solve the problem of poor service for households and businesses in communities served by a grid-connected Disco that provides poor service.

As we set out to write this book, we initially considered limiting the analysis to issues specific to interconnected mini grids, such as the price of bulk power purchases, firmness and hours of bulk power purchases, leasing rates for existing distribution equipment, and technical requirements for "islanding." (*Islanding* is the operation of the mini grid's generation and distribution system in electrical isolation from the main grid.) It quickly became apparent, however, that focusing solely on these issues would ignore the fact that undergrid mini grids are also affected by many decisions made by developers and Discos and by regulatory rules that apply to all mini grids. Accordingly, the book would be incomplete if we limited our observations and recommendations just to the subset of issues that affect only undergrid mini grids. Where appropriate, therefore, we also address issues that pertain to mini grids of all kinds.

The book is organized as follows. Chapter 1 discusses recent mini grid developments in undergrid areas of Nigeria and India. Chapter 2 presents five case studies of existing or proposed undergrid mini grids in Nigeria and India. Chapter 3 presents some initial observations on key policy and regulatory issues for mini grids. Chapter 4 discusses the building blocks for win-win-win outcomes for the interconnected mini grids, Discos, and their customers. Chapter 5 discusses the technical design and operation of interconnected mini grids. Chapter 6 presents some initial observations on how to promote the scale-up of mini grids. Chapter 7 offers recommendations for helping interconnected and non-interconnected mini grids become commercially and politically sustainable.

The analysis in this book is limited to actual or proposed undergrid mini grid projects developed by private entities other than the local Disco or a subfranchisee that has been granted the right to provide distribution services over a larger geographic area. The goal is to see what can be learned from implementation experiences at this very early stage.[7] Experience with interconnected mini grids in developing countries[8] is still limited; therefore, this book should be viewed as an initial reconnaissance or exploratory exercise.

Several proposed interconnected mini grid projects were delayed by the COVID-19 pandemic. Consequently, as of November 2023, only limited operating experience was available to review and evaluate. Nevertheless, we believe this limited experience is sufficient to warrant a preliminary scoping of ground-level implementation issues for interconnected and non-interconnected mini grids in undergrid areas.

GUIDE TO THE CASE STUDIES PRESENTED IN CHAPTER 2

An *undergrid area* is an area currently served by a Disco connected to the main grid but in which the service provided does not meet the needs of actual and potential customers.

As noted, chapter 2 presents five case studies of interconnected and non-interconnected mini grids in undergrid areas in developing countries. An *undergrid area* is an area currently served by a Disco connected to the main grid but in which the service provided does not meet the needs of actual and potential customers.[9]

The five mini grids in the case studies were all promoted and built by private developers, which took the lead in selecting the sites to be developed. They all are still owned and operated by private companies. Two (Toto and Wuse in Nigeria) are interconnected undergrid mini grids; three (Husk and Tata in India and Mokoloki in Nigeria) are non-interconnected. We decided to focus on privately owned and operated mini grids because in our experience privately owned mini grids (as opposed to community- and government-owned mini grids) have the greatest potential for achieving rapid, efficient, and sustainable scale-up.[10]

Appendix A describes three other approaches to promoting and developing mini grids:[11]

- Government-led competitive procurements for government-selected sites and zones
- Government-led competitive procurement in government-selected zonal concessions
- Utility-led procurements for the construction and initial operation of mini grids by private mini grid operators

We focus on private sector–led development of mini grid sites, combined with regulation or deregulation, because these are currently the dominant approaches in three large countries (India, Nigeria, and Tanzania). Thus, substantial on-the-ground experience can be observed and evaluated. But the starting conditions in these three countries—a strong domestic entrepreneurial class and national or regional utilities that are willing to allow nonaffiliated domestic and foreign private companies to own and operate mini grids in their franchise area—often do not exist in other developing countries. As other countries gain more real-world experience with the approaches described in appendix A, we recommend that similar case studies be developed for these different approaches.

We focus on private sector–led development of mini grid sites, combined with regulation or deregulation, because these are currently the dominant approaches in three large countries (India, Nigeria, and Tanzania).

One might reasonably ask why a mini grid is needed if a community is already being served by a Disco connected to the main grid. As noted earlier, the reality in many developing countries is that the Disco's electricity is often so unreliable or of such poor quality that it does not meet the community's needs. Under such circumstances, a commercial opportunity may exist for a developer to build a mini grid in the area if households and businesses are willing and able to pay a higher price for better service. In these five case studies, we dig deep into the commercial, technical, and regulatory implementation of privately initiated mini grids.

We limited the case studies to solar hybrid mini grids (solar + batteries + diesel and sometimes biomass) because this combination of technologies is expected to dominate new mini grid projects in Asia and Sub-Saharan Africa for the next several years or more. For interconnected mini grids, we examine mini grids that will be connected to the local Disco lines from day 1 of their operation. However, most of the implementation questions that we address for mini grids interconnected from day 1 are also relevant for mini grids that may connect to the main grid at some later time.

The case studies were researched and written in 2021 and 2022. In the second half of 2023, we went back to document the successes and failures that occurred in the intervening months.

NOTES

1. An electrical connection means that an electrical current can flow from the Disco to the customer's wiring.

2. This problem was recognized by the World Bank in 2015 (Bhatia and Angelou 2015), when it recommended a now widely cited Multi-Tier Framework to measure variations in the quality of electricity supply for connected customers. A valid criticism of the framework is that the middle tiers bundle the amount of power (wattage) and the hours of availability per day, failing to recognize the benefits of high-reliability mini grids even if they deliver lower wattage. The framework has been used to measure tiers of service in 20 countries, at a cost of about US$150,000 per study. Given this cost, such studies are not likely to be undertaken on a regular basis going forward. Annex 1 of Perez-Arriaga and others (2022) provides an excellent survey of the strengths and weaknesses of different approaches to measuring electricity access.
3. Nigerian businesses reported an average of 393 outages in 2014, with an average annual total duration of 4,465 hours (IFC 2019). This figure implies that Nigerian businesses experience grid outages 52 percent of the time.
4. Ferrall, Jacquiau-Chamski, and Kammen (2022) argue that SAIDI and SAIFI are not useful measures of progress toward meeting SDG7 because they fail to reflect three key aspects of outages: the reasons for the outages, the timing of the outages, and the fairness of the distribution of the outage.
5. This reliability standard is stricter than the one used in the World Bank's Multi-Tier Framework. Tier 5, the top tier in that framework, allows for 3 unplanned outages per week (more than 150 unplanned outages per year).
6. The Real-Time Electricity Supply and Quality Tracker project is an ongoing initiative to obtain more accurate information on SAIDI, SAIFI, and voltage-variation data for main grid–supplied electricity in major cities in eight African countries. Low-cost meters (currently about US$80) measure and transmit these parameters in real time via existing Global System for Mobile Communication networks. The early evidence suggests that SAIDI and SAIFI performance is much worse than recorded in official government and utility statistics. The project has **not** tracked mini grid reliability and quality (for details, refer to Moss 2021). In India, the Prayas Energy Group's Electricity Supply Monitoring Initiative (http://watchyourpower.org/), which has been discontinued, provided detailed data-logged and reliability data for real-time electricity supply for several states.
7. This book has greatly benefited from the assistance of the German Agency for International Cooperation (GIZ). GIZ is helping the Nigerian government manage the Interconnected Mini-grid Acceleration Scheme, or IMAS (discussed in appendixes C, I, and J), which provides in-kind grants and technical assistance to competitively selected local private interconnected mini grid developers. The scheme appears to be one of the first donor initiatives, if not the only one, that focuses exclusively on interconnected mini grids. GIZ and its consultants (Integration Environment and Energy) have estimated how changes in load factors, grants, and electricity purchases affect the levelized cost of electricity for the scheme's first six proposed interconnected mini grid projects (refer to chapter 4).
8. We use the term "developing countries" to refer to low- and middle-income countries that are characterized by inadequate electricity access, unreliable service, or both.
9. Nagpal and Perez-Arriaga (2021, 4–5) use a broader definition of the term *undergrid mini grids*. In addition to the interconnected and non-interconnected mini grids that are the focus of this book, those authors include two other business models in defining undergrid mini grids. The first is an operator that provides generation, storage, or both to "improve the power quality at the tail end of the rural feeder," but "without engaging in any distribution activities." The second is an operator that engages in billing and collection activities or in the development of productive end uses without owning or operating any generation or distribution facilities.
10. A recent *Washington Post* article on mini grid development in India (Mehrotra 2023) reports that only 5 percent of 3,300 mini grids financed and owned by the government are still operational. The article states that private mini grid companies in India "have a better record in maintaining the systems because their revenue models are stronger." The article provides no statistics to support the difference in performance between these two ownership models.
11. These three approaches are being pursued in the Democratic Republic of Congo, Ethiopia, and Kenya.

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1 Mini Grids in Undergrid Areas in Developing Countries

"You speak a language that I understand not."

—Queen Hermione, from *The Winter's Tale,* by William Shakespeare

WHAT IS A MINI GRID?

No single definition of a mini grid is universally accepted (refer to appendix D).[1] For the purposes of this book we define a mini grid as follows:

> A mini-grid is a low-voltage (up to 1,000 volts) or medium-voltage (up to 35 kilovolts) distribution grid that receives electricity from one or more small generators and supplies electricity to a target group of consumers, typically including households, businesses, and public institutions. It is typically located near the loads that it serves. A mini grid can be fully isolated from the national grid or interconnected to it. If it is interconnected to the national grid, it must also be able to isolate ("island") from the national grid and continue to serve its customers while operating in island or autonomous mode.

This definition is broad enough to cover both interconnected and non-interconnected mini grids.

Non-interconnected, geographically isolated mini grids have been the dominant type of mini grid in developing countries.

An interconnected mini grid is a mini grid that can, with the closing of a switch on an existing physical line, connect with the main grid, usually through a distribution company (Disco), with the possibility of power flowing either from or to the main grid. A non-interconnected mini grid does not have a physical connection to a local Disco. Non-interconnected, geographically isolated mini grids have been the dominant type of mini grid in developing countries. In contrast, physically interconnected mini grids have been the dominant type in most developed countries (box 1.1).

BOX 1.1

Mini grids in developed and developing countries

Significant differences exist between the mini grids being developed in the United States and other countries of the Organisation for Economic Co-operation and Development (OECD) and those being developed in Sub-Saharan Africa and Asia:

- Most mini grids in the United States and other OECD countries are currently designed to serve a single customer. In contrast, most mini grids in developing countries are designed to serve multiple customers.
- Most mini grids in OECD countries are typically connected to the main grid from day 1, whereas most in developing countries are electrically isolated (non-interconnected).
- OECD mini grids are generally built to provide exceptionally high levels of reliability for critical loads (for example, data centers or hospitals) on national grids that are already generally reliable. Mini grids in developing countries, by contrast, provide reliable (but not necessarily ultra-reliable) electricity for people who previously had, at best, very unreliable service.

Over time, the differences between the two types of mini grids will probably narrow, as both the number and variety of mini grids increase in both developing and high-income countries. (For details, refer to appendix E.)

A mini grid is a type of distributed energy resource (DER). A DER is "anything that generates, stores, or manages electricity on distribution grids" (Roberts 2021, 3). A DER can be a demand- or supply-side resource. It can be located on a distribution system, at a distribution substation, or behind a customer meter. DERs can take many forms: rooftop solar, building storage, consumer batteries, intermittent generation, distributed generation, demand response, energy efficiency, thermal storage, or electric vehicles and their charging equipment.

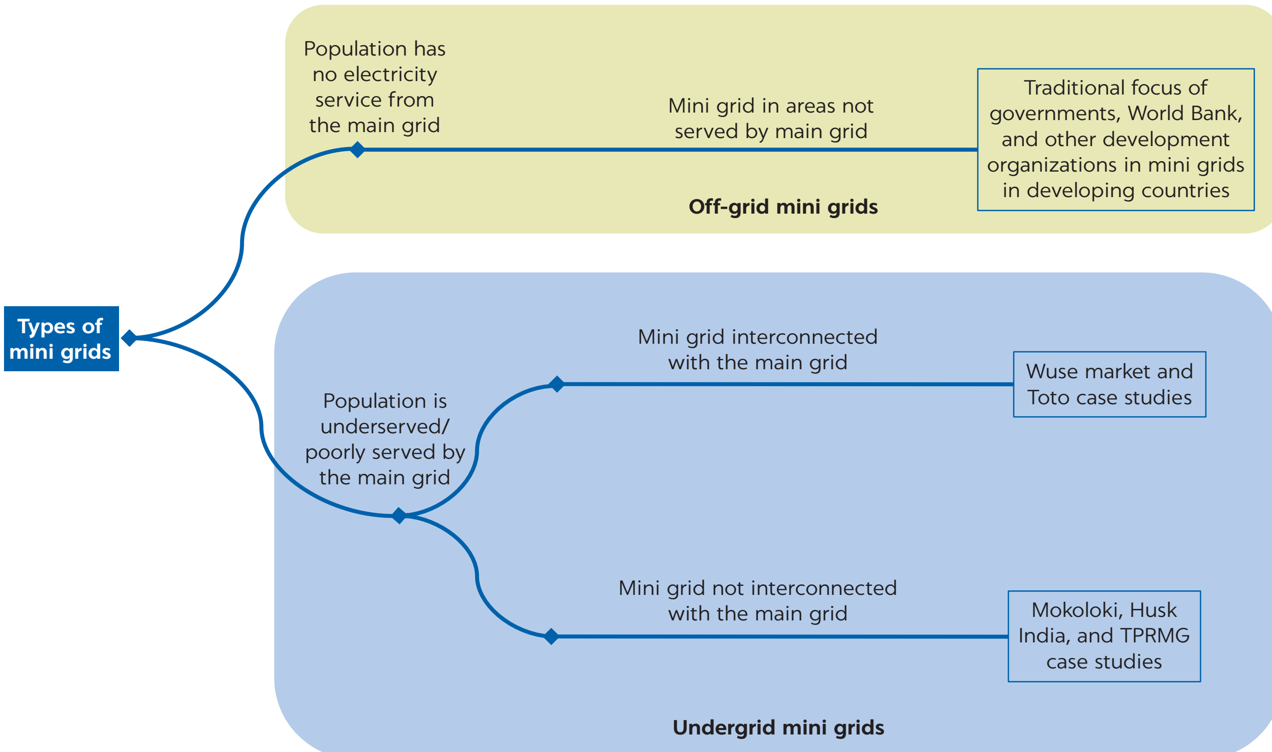
The Rocky Mountain Institute (RMI) has developed a typology of possible utility-enabled DER business models for Nigeria (Sherwood, Tubb, and Olatundi 2022). In countries with organized wholesale markets, DERs can earn additional revenues by participating in these markets. For example, in the United States, Order 2222, issued in September 2020 by the Federal Energy Regulatory Commission, mandates that the country's six regional transmission organizations must allow aggregated DERs to bid into regional energy and ancillary service markets. The grid services that could be provided by mini grids in organized wholesale markets are described in chapter 5.

SERVING UNDERSERVED AREAS

When government officials in developing countries talk about mini grids, they are usually referring to self-contained generation and distribution systems built and operated in remote rural villages that have not been reached by the main grid (refer to figure 1.1, upper branch). These mini grids, which are both geographically and electrically isolated, are typically created to provide an initial level of alternating current or direct current electricity in an unserved area, at least until the main grid arrives. Until recently, the technical and financial support of the World Bank and other development organizations has targeted electrically isolated mini grids built and operated in areas that are not receiving any electricity service from Discos connected to the main grid.

FIGURE 1.1

Types of mini grids and their relationships to the main grid



Source: Original figure created for this publication.
Note: TPRMG = Tata Power Renewable Microgrid.

Recently, interest has grown in building and operating mini grids in underserved areas of developing countries—regulatory euphemism for areas with poor service (refer to figure 1.1, two lower branches). Service may be unsatisfactory because the Disco's physical facilities are in poor condition, the Disco is unable to acquire a reliable supply of electricity from upstream sources, or the Disco's technical and commercial services are poor.

Recently, interest has grown in building and operating mini grids in underserved areas of developing countries—regulatory euphemism for areas with poor service. Service may be unsatisfactory because the Disco's physical facilities are in poor condition, the Disco is unable to acquire a reliable supply of electricity from upstream sources, or the Disco's technical and commercial services are poor.

Poor service has different dimensions. On many days, the Disco may be able to provide only a few hours of service or the quality of the electrical supply may be poor because of wide variations in voltage and frequency. Many Discos lack the capital to install meters for all household customers. As a consequence, many bill on an estimated rather than a metered basis, a practice that leads to frequent disputes about the accuracy of the bills. Service is also poor because tariffs are kept low for political reasons, making it difficult or impossible for Discos to recover their operating costs (Trimble and others 2016).

Mini grids in underserved areas are referred to as undergrid mini grids when a local Disco's distribution lines already exist at the location. An isolated undergrid mini grid has no functioning electrical connection to the local Disco's distribution system, whereas an interconnected mini grid, as previously noted, has an electrical connection to the Disco's distribution lines.[2] The existence of an electrical connection between the mini grid and the local Disco allows for purchases or sales of electricity between the two systems. Whether the mini grid in an underserved area is interconnected or non-interconnected, it may choose to lease the Disco's distribution lines in place rather than build a separate new distribution system.

Major ground-level initiatives to establish undergrid mini grids are under way in Nigeria and India. In Nigeria, the Rural Electrification Agency has initiated the Nigeria Electrification Project, financed by the World Bank, to create interconnected mini grids in three market segments: large urban marketplaces, rural villages, and universities and hospitals. Another program, the Nigerian Energy Support Programme (NESP), is providing grants and technical assistance to Nigerian developers that propose to build interconnected mini grids.[3] The interconnected mini grids created by these two programs will be connected to Nigeria's 11 privately owned Discos.

In India, Tata Power, the country's largest integrated power company, has created the Tata Power Renewable Microgrid (refer to case study 4 in chapter 2), a subsidiary that proposes to develop 10,000 microgrids with support from the Rockefeller Foundation. Tata's business model emphasizes creating non-interconnected undergrid mini grids in villages that already receive some service from state-owned Discos connected to the main grid. Husk Power, a mini grid company that operates in both India and Nigeria, also operates non-interconnected mini grids in undergrid areas of India. However, in Nigeria, it expects to build and operate interconnected mini grids in the service area of 1 of Nigeria's 11 Discos.

WHAT IS AN INTERCONNECTED MINI GRID?

As previously stated, an interconnected mini grid is electrically connected to a Disco's existing grid such that electrical energy can safely flow across the boundary between the two systems. The electrical connection could exist on day 1 of the mini grid's operation or at some later date when the main grid arrives at a village or town that was previously served by an electrically and geographically isolated mini grid.[4] If the developer chooses to locate the mini grid in a town or village already served by a Disco (a widespread phenomenon in India), it will become an interconnected mini grid when it connects electrically to the Disco by closing the switch on wires between the smaller mini grid distribution system and the larger distribution system. (A prior physical connection may exist between the two systems, but that connection is not an electrical connection until the switch is closed.)

The focus of this book is on interconnected mini grids serving communities and urban marketplaces. The five case studies are limited to these two market segments, though others are possible (refer to box 1.2). Interconnected mini grids could also be built to serve other types of customers, such as commercial and industrial (C&I) installations, public institutions, and gated communities. A report from the Rocky Mountain Institute (RMI) proposes a win-win-win business model to create and operate interconnected mini grids for C&I customers (Sherwood, Tubb, and Olatundi 2022). The promotion of interconnected mini grids is an important component of a new World Bank project under consideration for Nigeria.[5]

BOX 1.2

Alternatives to mini grids: Small power producers and small power distributors

A mini grid is not the only village-level entity that can be connected to the main grid. Small power producers and small power distributors can also be connected.

An interconnected small power producer sells its generated power to the owner and operator of the main grid or some other entity connected to the main grid but does not sell at retail to local customers. A small power distributor buys all (or most) of its supply from the main grid operator or one or more generators or other suppliers connected to the main grid and then resells this electricity to its retail customers in the village.

The interconnected mini grids explored in this study are like small power distributors in that they purchase electricity from the main grid for resale to local households and businesses that are connected to a distribution grid. The mini grid owns the distribution grid outright or leases it from the distribution company (Disco). Because the power supplied by the main grid may be unreliable, however, most of the interconnected mini grid's generation comes from the mini grid's own generation assets. In theory, interconnected mini grids can also sell electricity to the main grid, like small power producers, although none of the subjects of the case studies in chapter 2 currently does so.

MINI GRID SALES TO, AND PURCHASES OF ELECTRICITY FROM, THE DISCO

When the mini grid is interconnected to the Disco (or other main grid–connected entities), it can buy electricity from or sell electricity to the Disco. Purchases are more common than sales, at least initially. If the Disco is connected to national transmission lines, it is generally able to offer wholesale tariffs for electricity that are low enough to be attractive to the mini grid, even if that supply of electricity is not always reliable. At a later stage, the mini grid may be able to offer grid support services (discussed in chapter 5).

When the mini grid is interconnected to the Disco (or other main grid–connected entities), it can buy electricity from or sell electricity to the Disco.

Sales of electricity from the mini grid to the Disco are likely to occur under two sets of circumstances. The first is when the mini grid has surplus energy (when its batteries are full, its loads are low, and the sun is shining) and it is financially advantageous to sell electricity, even at a low tariff, because the alternative is for the mini grid's controller or photovoltaic inverter to curtail power from the panels, which in effect is dumping electricity. The second is when the Disco has high demand for electricity and is willing to pay a premium that will cover the mini grid's cost of production (and, if during nonsolar hours, its storage or diesel generation costs). (Tariffs for electricity sales to and from the mini grid are discussed in more detail in chapter 3.)

Operators of interconnected mini grids face risks for both purchases and sales. For purchases, the principal risk is that the Disco will not be able to provide the electricity it promised to sell to the mini grid. If this happens, the mini grid operator will be forced to make up the shortfall from batteries or backup diesel generation, and both of these sources are likely to be more expensive. For sales, the risk is that the mini grid will not be paid (or will be paid with delay) for the electricity it supplied to the Disco.

If the mini grid leases the Disco's distribution grid in the village (which seems likely to become the dominant approach in Nigeria but not in India, at least at present), a third transaction may take place: the Disco will receive lease payments for the mini grid's use of its distribution lines. These payments, known in Nigeria as Distribution Use of System charges, are not limited to interconnected mini grids. They will also be paid by non-interconnected undergrid mini grids if they choose to use some or all of a Disco's existing distribution system (see the Mokoloki case study in chapter 2).

THE REGULATORY FRAMEWORK FOR INTERCONNECTED MINI GRIDS

The regulatory framework for interconnected mini grids is already in place in several Sub-Saharan African countries. The 2016 mini grid regulations of the Nigerian Electricity Regulatory Commission (NERC), formally issued in 2017, define an interconnected mini grid as "a Mini-Grid that is connected to a Distribution Licensee's network." NERC encourages interconnected mini grids for areas in which customers are served by "an existing but poorly supplied or non-functional distribution system" (NERC 2016, 7–8). To facilitate investments in interconnected mini grids, NERC's regulations include a model tripartite agreement between the interconnected mini grid developer, the local Disco, and a community or customer organization in the village or marketplace where the interconnected mini grid would be located.

Regulations for interconnected mini grids are also in place in Rwanda and Sierra Leone. Myanmar and Papua New Guinea have also drafted regulations. In India, the mini grid regulations of the states of Madhya Pradesh, Odisha, and Uttar Pradesh enable the interconnection of mini grids with the main grids (RMI 2020) but interconnections have not yet taken place. The fact that interconnected mini grids are allowed in a country's electricity regulations is no guarantee that they will actually come into existence. As the case studies in chapter 2 show, legal permissibility does not guarantee commercial viability.

Legal permissibility does not guarantee commercial viability.

WHAT IS AN ISOLATED OR NON-INTERCONNECTED MINI GRID?

As noted earlier, an isolated mini grid is one that is not physically connected to the existing wires and transformers of a Disco. Although the absence of a physical connection usually also implies an isolated geographic location, this is not always the case. To make the distinction clearer, the International Renewable Energy Agency refers to isolated mini grids as "autonomous mini grids," where *autonomous* refers to physical and electrical separation from any other electrical supply system (IRENA 2018, 7). Confusion arises because the term *electrical isolation* is often used synonymously with *geographic isolation*. This confusion is understandable because mini grids in developing countries have historically been built and operated in villages and towns that were also geographically isolated.

Electrical isolation does not require geographic isolation. It is possible to have electrically isolated mini grids even in villages that already have an operating Disco—as India does. In March 2019, India's central government reported that main grid–connected distribution lines had reached virtually every village in the country through the Saubhagya initiative.[6] Even in villages served by Discos connected to the main grid, however, private mini grid companies like Husk and Tata have invested in physically and electrically isolated mini grids. As of March 30, 2023, for example, all but 2 of the 615 operating mini grids supported by Smart Power India (a subsidiary of the Rockefeller Foundation) were built to operate in villages where distribution lines and transformers owned and operated by a state-owned Disco were already in place before the mini grid arrived.[7] Presumably, Husk, Tata, and other mini grid developers built mini grids in these towns and villages because they believed that households and businesses would be willing to pay higher prices for reliable and stable electrical service. In these villages, it is not uncommon to see separate distribution lines on the two sides of the same street.[8]

In Indian villages with dual distribution systems, households and businesses often have two connections: one to the existing Disco and the other to the new mini grid enterprise. These two physical connections allow for head-to-head retail competition between the Disco and the mini grid within the same premises. The two separate connections allow customers to buy electricity from the supplier that offers the lowest price (and actually has electricity to sell) at any given time.

Having two separate and redundant physical distribution systems in a single village is wasteful. The norm in the United Kingdom and the United States, for example, is that retail competition takes place over a single set of distribution lines and a single connection line into each customer's premises. As discussed in the case studies, the decision to create new and electrically separate non-interconnected distribution systems in India in communities already served by a main grid–connected Disco may be a rational business decision for an individual mini grid developer, but it leads to duplicative investments in distribution.

A different approach is under way in Nigeria. In a 2019 report, RMI proposes "minigrids that utilize existing distribution and are powered by distributed energy resources" (RMI 2019, 7). RMI is working with mini grid developers in Nigeria to lease the local Disco's existing distribution system in the village or town rather than building a separate new distribution system (see the Mokoloki, Toto, and Wuse case studies in chapter 2).

The isolated mini grids in India and the mini grids in Nigeria differ in other ways, as well. In India, from day 1 there is no electrical connection between the new mini grid and the existing Disco: the mini grid company builds a new distribution network that operates separately but alongside the existing Disco's network. In contrast, in Nigeria, the mini grid company leases grid poles and wires from the Disco. In one case (Mokoloki), as noted earlier, the mini grid (at least initially) operates these facilities in an electrically disconnected mode (that is, the switch between the two systems is in the open position) from the Disco but with plans to become interconnected. In a second case (Toto), the mini grid operator will lease some of the Disco's facilities, with plans to be electrically connected (that is, the switch is closed) to the rest of the Disco's system from day 1. If the Disco is a reliable supplier, the Toto mini grid will be able to buy electricity from the Disco at a relatively low cost and in turn be able to reduce the number of backup batteries it installs. In addition to these capital cost savings, the interconnection will allow Toto to reduce the number of hours needed to generate electricity from its on-site diesel generators with higher running costs. (Refer to chapter 4 for specific estimates of the capital and operating cost savings for interconnected mini grids.)

Privately owned interconnected solar hybrid mini grids can be commercially, technically, and politically viable only if they create a win-win-win economic outcome for the mini grid owner-operator, the Disco, and the customers served by the mini grid.

THE NEED FOR WIN-WIN-WIN BUSINESS MODELS

Privately owned interconnected solar hybrid mini grids can be commercially, technically, and politically viable only if they create a win-win-win economic outcome for the mini grid owner-operator, the Disco, and the customers served by the mini grid.[9] It is not enough for an interconnected mini grid to be commercially viable for its private developer alone. The mini grid must also provide commercial benefits for the Disco to which the mini grid proposes to connect. The customers already being served by the Disco must also see some benefit in switching over to become customers of a mini grid.

Usually, the higher degree of reliability is what persuades some customers to buy electricity from the mini grid at a higher price than they were paying for electricity from the existing local distribution utility.[10] How much of a premium different customer groups are willing to pay for more reliable electricity supply is unclear, though it seems likely that industrial and commercial customers would be willing to pay a higher premium than would residential users. This likelihood, combined with the much lower cost of supplying daytime power, highlights the importance of commercial and industrial customers in a community mini grid or in a separate mini grid that is built and operated to serve only C&I customers. (C&I mini grids are not examined in any detail in this study.)

TWO POSSIBLE CRITICISMS OF THE SCOPE OF THIS BOOK

Criticism 1: Mini grids do not solve the problem of poorly performing Discos

If the underlying problem is a poorly operated and underfunded main grid, would it not make more sense to emphasize initiatives that improve the overall performance of public and private generation, transmission, and distribution enterprises that are already connected to the main grid? Does promoting mini grids, which can provide a solution for those customers willing to pay, divert attention—and, in the long run, resources—from broader reforms that might improve service for everyone more economically and more equitably?

Undergrid mini grids can serve as one element of a broader framework to improve the performance of poorly performing Discos connected to the main grid. For customers poorly served by an existing Disco, these mini grids can provide a partial answer when attempts to improve the operating and financial performance of existing Discos have been slow to yield results. Mini grids for underserved grid-connected customers are an immediately available means in the tool kit of policy makers and planners that should be deployed in concert with robust programs to expand electrification and the quality and reliability of supply on the national grid. If reforms of poorly performing Discos are slow to produce results or fail altogether, undergrid mini grids can provide new and more reliable service.[11] To use a soccer analogy, we are looking for good short passes to move the ball forward rather than depending on one long pass to achieve Sustainable Development Goal 7: universal and reliable electrification.

Criticism 2: Mini grids are too narrow a technical solution

A second criticism is that mini grids are too narrow a solution, because they rely on a single electricity delivery option that may be feasible in only a limited number of locations. It has been argued that a better approach would be to create private "energy companies of the future," sometimes referred to as "integrated Discos," or an "integrated distribution framework" (Dayal 2019; Jacquot and others 2022; Perez-Arriaga and others 2021; Power for All 2019; Shell Foundation 2019). The essence of this approach is that a private company would be granted a subconcession or subfranchise by an existing licensed Disco to become the new service provider in a large geographic area within the Disco's specified service area.[12] Unlike a private mini grid developer, this new company would not be limited to a single electricity delivery technology. Instead, the new subconcessionaire could use multiple delivery options, such as grid extensions, on-site generators, solar home systems, and isolated and interconnected mini grids. The subconcessionaire would have the flexibility to choose an electricity delivery technology, based on or off the grid, that is tailored to the size, economic needs, and location of the individual customer, rather than being limited to a mini grid technology.

The NERC approved this approach in February 2020 for a project proposed by the Kaduna Electricity Distribution Company and Konexa, a private company (Sunday 2020). In May 2021, Konexa announced that it had signed an agreement with another Nigerian Disco, the Kano State Electricity Distribution Company, to build 10 megawatts of renewable generation by 2022. The Abuja Electricity Distribution Company, another one of Nigeria's 11 private Discos, proposed a related approach, the Distributed Energy Solutions Strategy (described in the Toto interconnected mini grid case study in chapter 2).

Both Konexa and the Abuja Electricity Distribution Company propose multiple delivery options to provide improved electricity service to different customer groups. In addition to main grid connections and solar home systems, interconnected and isolated mini grids could be two of these options. Because both approaches—the granting of larger geographic subconcessions or the issuance of a smaller mini grid permit (1 megawatt or smaller)—are just being developed, it is too early to know whether either will be commercially sustainable. More on-the-ground experience is needed with the two approaches before conclusions can be reached about their relative strengths and weaknesses.[13]

We have seen no evidence that the two approaches are incompatible. If and when a larger distribution subfranchise is created, the entity granted the new subfranchise could be given the legal right to buy out any mini grids that are already operating in the subfranchisee's awarded service area. Alternatively, the subfranchisee could decide to interconnect to the mini grid and buy electricity from, and sell electricity to, the mini grid, an emerging trend in Organisation for Economic Co-operation and Development countries. Subfranchises take time to design and operationalize. The benefit of pursuing these parallel approaches is that communities will receive electricity from the mini grid during what could be a lengthy gestation period needed to create a commercially viable Disco subfranchise.

NOTES

1. Appendix D includes 10 definitions of mini grids that have been used by various organizations. General agreement is that a solar photovoltaic array without either battery storage or diesel generation is not a mini grid, because it cannot operate autonomously to match local demand and supply.
2. RMI uses a broader definition. It defines interconnected mini grids to include both mini grids that are electrically isolated from the main grid and mini grids that are electrically connected to the main grid—as long as they operate in an underserved community (RMI 2018). In contrast, we limit the term *interconnected mini grid* to mini grids that operate in underserved areas *and* have a functioning electrical connection that allows the mini grid to buy from or sell electricity to the local Disco.
3. The NESP component that promotes interconnected mini grids is known as the Interconnected Mini-grid Acceleration Scheme, or IMAS (refer to appendixes B and C).
4. An Energy Sector Management Assistance Program (ESMAP) study (Tenenbaum, Greacen, and Vaghela 2018) describes what happened to isolated mini grids in Cambodia, Indonesia, and Sri Lanka when the main grid arrived in their villages. In Indonesia and Sri Lanka, most of the community-owned and community-operated micro-hydro-powered mini grids went out of existence and the mini grid's customers became customers of the government-owned national utility. The experience was different in Cambodia, where most of the 250 previously isolated mini grids became privately owned small power distributors. When the national utility's main grid arrived, the mini grids switched from diesel generators to buying electricity at wholesale from the national utility and reselling it to retail customers they had previously supplied with diesel-generated electricity. The case studies in these three countries may have limited predictive value for privately owned and operated solar hybrid mini grids, the subject of this book.
5. World Bank president Ajay Banga recently announced that the World Bank is considering a new project to promote the construction and operation of 1,000 new mini grids in Nigeria (Reuters 2023). On December 14, 2023, the World Bank Board approved the Nigeria Distributed Access through Renewable Energy Scale-up (DARES) project, which includes an allocation of US$127 million specifically for interconnected mini grids. The project targets the development of 125 interconnected mini grids that are expected to leverage US$296 million in private capital. In January 2024, NERC published a new mini grid regulation (NERC 2024) that captures some recommendations in this book, including portfolio applications for isolated and interconnected mini grid permits, the possibility of filing a single tariff application for all mini grids in a portfolio, and the ability to transfer mini grid permits to other entities. This new mini grid regulation should provide an improved regulatory environment that will support implementation of the new scale-up project.
6. Under the Saubhagya initiative, households qualifying as being below the poverty line received free grid connections. According to the India Ministry of Power's Saubhagya web page, households above the poverty line had to pay only Rs 500 (US$6.90) for a connection and could pay in monthly payments on their electricity bills. Commercial and industrial customers did not qualify for a connection subsidy; they paid the full connection cost of Rs 2,000–3,000 (US$27.60–US$41.40) (https://powermin.gov.in/en/content/saubhagya, accessed December 10, 2022). In converting Indian rupees to US dollars, we used the June 6, 2021, exchange rate of US$1.00 = Rs 72.46.
7. Rahul Kandoi. Email communication with Ashish Shrestha, March 29, 2023.
8. In India, this arrangement is sometimes referred to as operating in parallel. The Indian meaning is that the two systems operate side by side without any physical interconnection. However, in the engineering literature, the phrase "operating in parallel" has a very different meaning. To an engineer, operating in parallel means that the two systems are electrically connected, with current able to flow from one system to the other. For this reason, we prefer the term *non-interconnected*.
9. We assume that the mini grid is developed and operated by a private mini grid enterprise that is legally separate from the local Disco. If the mini grid is owned and operated by the Disco or a company that it hires to operate the mini grid, no formal buy-in is required from the customers in the community served by the mini grid. From the perspective of customers in the community served by the mini grid, the Disco, or a designated subconcessionaire (like Konexa in Nigeria), is still their supplier.
10. The retail tariffs charged by mini grids are known to people in the villages served by the mini grid. However, neither India nor Nigeria appears to have a publicly available national

database of mini grid tariffs. Information on tariffs for some Indian mini grids is reported in the following two published articles. In the first article, the Mlinda mini grids in the Indian state of Jharkhand are reported to charge a daytime tariff of US$0.32 per kilowatt-hour (kWh) and a nighttime tariff of US$0.64/kWh (NRDC and CEEW 2021, 7). These tariffs are three to seven times higher than the main grid electricity tariffs. In a second article, Sharma, Agrawal, and Urpelainen (2020) estimate that, in 2018, households paid about US$0.55/kWh for mini grid electricity versus US$0.11/kWh for main grid electricity (when it was available). These estimates were based on a sample of more than 50 villages in four Indian states.

11. In December 2019, Nigeria's national electricity regulator concluded that the 11 Discos created in 2013 "are unable to satisfactorily meet stakeholder's expectations in the provision of access to safe and reliable electricity services" (NERC 2019, 3).
12. Throughout this book, we use the terms *concession, license,* and *franchise* interchangeably. However, there are important differences between a concession and a license, which are described in chapter 3. As commonly used, all three terms refer to a government-granted right to provide one or more specified services, usually on an exclusive basis, for a defined period in a specified geographic area. A subconcessionaire (or sublicensee or subfranchisee) is an entity that assumes (with government approval) all the obligations that were assigned to the original concessionaire or licensee for some or all of the time remaining in the original concession or license. A subconcessionaire, sublicensee, or subfranchisee may assume these obligations for a small or large geographic area within the original concession, license, or franchise area. A mini grid operating in a town or village is one type of subconcessionaire. Refer to Hosier and others (2017) for a comprehensive description of how concessions have been used to promote rural electrification in Sub-Saharan Africa. Refer to NERC (2019) for the regulator's initial thinking on subfranchising. NERC defines a *subfranchise* as an entity that may provide one or more services (for example, metering, billing, collections, and maintenance of lines) or all service responsibilities of the Disco.
13. A third approach in Nigeria is the Premium Grid Initiative being promoted by the European Union and the German Agency for International Cooperation (GIZ) under the NESP. Like Konexa, it would create a subfranchise in an existing Disco service area that would be anchored by a large industrial or commercial load. Unlike Konexa, the Premium Grid Initiative would rely solely on grid-supplied electricity (for example, Disco electricity and electricity generated from embedded generators using hybrid solar, reciprocating generators, and battery storage). Unlike the Konexa initiative, the Premium mini grid operator will not use mini grids or solar home systems to serve any of its subfranchise customers. For either initiative to be financially viable, a large share (perhaps greater than 70 percent) of the total electricity of the Konexa and Premium grids must be sold to commercial and industrial customers.

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2 Case Studies from Nigeria and India

GOVERNMENT AND PRIVATE SECTOR APPROACHES TO PROMOTING MINI GRIDS

The many business models for mini grids may be differentiated by who finances, builds, owns, and operates them (Tenenbaum, Greacen, and Vaghela 2018). Knuckles (2016) applies the general business model literature to the case of 24 mini grids in developing countries and concludes that mini grid businesses differ across four key dimensions: customer identity (Who is the customer?), customer engagement (What products and/or services does the firm sell?), value chain links (How is customer satisfaction delivered?), and monetization (For whom, how, and when is money made?).

The five case studies from Nigeria and India presented in this chapter describe privately financed, built, and operated mini grids at sites selected by a mini grid developer with little or no government guidance. This bottom-up delivery model appears to be working (at least so far) in Nigeria and India, but that does not mean it will work in other Sub-Saharan or Asian countries or that all investors or developers prefer it.

The five case studies of mini grids in Nigeria and India presented in this chapter describe privately financed, built, and operated mini grids at sites selected by a mini grid developer with little or no government guidance.

The business model that a mini grid developer selects depends on how a country's government decides to promote mini grids. Table 2.1 describes five approaches being used to promote mini grids in Sub-Saharan Africa and Asia. Appendix A analyzes the pros and cons of each approach.

A government's choice of delivery model is constrained by the country's starting conditions (including the commercial and operating performance of existing main grid companies, the availability of subsidies, and political constraints). A government may choose more than one approach; for example, Nigeria is pursuing a developer-led, bottom-up approach in parallel with competitive procurement for government-selected sites. The Democratic Republic of Congo and Kenya are testing multiple government-promoted approaches.

This book focuses on the first approach because it appears to be the most widely implemented. The case studies suggest that this approach has considerable potential for rapid and sustainable scale-up of off-grid and undergrid areas in many large, developing countries. In India, the developer-led model dominates and has led to the construction and operation of over 615 undergrid mini grids in

TABLE 2.1 Five approaches to promoting mini grids

APPROACH	DESCRIPTION	EXAMPLES
Sites selected and operated by private developers	Domestic and foreign developers will look for individual mini grid sites they think can be made profitable. This approach usually has licensing/permit requirements along with some tariff regulation.	Nigeria and Tanzania
Private developer selection of sites is combined with deregulation	The mini grid developer can sell electricity without acquiring a license or permit and without regulatory approval of its retail tariffs.	India
Competitive procurement for government-selected sites	Top-down procurement for specific communities chosen by one or more government entities. The communities are usually grouped in the same geographic area to yield investment and operating efficiencies.	Nigeria, Sierra Leone, and Uganda
Competitive procurement for government-selected zonal concessions	A top-down zonal concession is a formal contract between a government and a private operator that specifies the rights and obligations of both parties. Among other things, it is designed to provide a stable and predictable regulatory regime.	Democratic Republic of Congo
Utility procurement for construction and initial operations and maintenance by private developers	The national utility contracts with one or more private mini grid developers for the construction and operation of mini grids for a specified period. At the end of this initial period, the national utility is expected to take over operation of the constructed mini grids.	Kenya and Ethiopia

Source: Original table compiled for this publication.

three states. The Indian approach is sometimes referred to as the "unlimited open market" delivery model. Meanwhile, under Nigeria's private developer–led delivery model, developers choose sites and need not wait for the government to complete procuring mini grid equipment or for the creation of legal public-private partnerships.[1] In both countries, growing evidence shows acceleration of mini grid development, equipment standardization, and declines in capital and operating costs.

The bottom-up approach, led by the private sector, does not mean that governments are not involved. In African countries that have pursued this approach, governments have typically helped private developers in at least three ways:

1. Gathering community data on the socioeconomic conditions, physical infrastructure (for example, number of buildings, telecommunication towers, roads, and reservoirs), and electrical infrastructure (on-site generators and solar home systems) of potential sites and making these data available to private developers
2. Providing up-front capital cost grants (usually with donor support) to reduce mini grid tariffs to more affordable levels
3. Helping developers obtain regulatory approval.

All the mini grids in the case studies described in this volume were built to function as undergrid mini grids from the very beginning of their operation. Many of the operational, commercial, and regulatory issues faced by these mini grids will also be encountered by mini grids that are initially isolated but become interconnected when the main grid is introduced at some later date.

TARGET MARKETS FOR PRIVATE INTERCONNECTED MINI GRIDS IN UNDERGRID AREAS

Privately owned and operated interconnected mini grids in undergrid areas can serve four main market segments:

1. Rural and peri-urban towns and villages
2. Large urban market centers with intermittent electricity supply
3. Commercial and industrial (C&I) installations[2]
4. Universities, hospitals, and health centers.

This book examines the first two segments. Future work should study interconnected mini grids in the last two segments.[3]

It is easier to achieve commercial viability in some markets than in others. An interconnected mini grid serving a large urban market center with a relatively large daytime load that coincides with the mini grid's solar-generation output is more likely to be commercially viable than an interconnected mini grid serving a rural village with low-demand households, an evening peak, and a limited initial commercial base. All else being equal, a mini grid developer will prefer installing an interconnected mini grid in a large urban marketplace.

An interconnected mini grid serving a large urban market center with a relatively large daytime load that coincides with the mini grid's solar-generation output is more likely to be commercially viable than an interconnected mini grid serving a rural village with low-demand households, an evening peak, and a limited initial commercial base.

The underlying economics of building a mini grid to serve C&I installations are probably even better, because larger C&I customers may be willing and able to sign long-term power purchase agreements (PPAs) with mini grid developers. However, isolated C&I mini grids promoted by private developers are problematic for distribution companies (Discos). If a C&I customer decides to entirely self-supply (that is, is no longer a Disco's customer) by withdrawing electricity from an on-site mini grid, then the Disco will lose significant revenue—revenue that had probably been used to subsidize grid-connected household customers.[4]

LONG-TERM POWER PURCHASE AGREEMENTS VERSUS NONCONTRACTUAL SALES

An interconnected mini grid serving an individual industrial facility will almost always have a long-term PPA with the mini grid's developer.[5] Signing a long-term PPA with one or more commercially credible buyers makes it easier for developers to obtain debt and equity financing.

The many smaller potential customers of an interconnected mini grid serving a peri-urban area or a rural town will be neither willing nor able to sign long-term PPAs with the mini grid developer. These mini grids will not have the financing advantage of potentially stable cash flows from their customers. The financial viability of a mini grid project will be "based on the assumption that customers will steadily grow their consumption" (CrossBoundary Energy Innovation Lab 2020).

OVERVIEW OF THE CASE STUDIES

The five case studies are based on almost 50 interviews with developers, Disco executives, consultants, and government officials.[6] Three of the case studies are from Nigeria and two from India,[7] and all five describe mini grid projects that were built to serve undergrid areas. Two (Toto and Wuse) are electrically connected to the local Disco, whereas three (Mokoloki, Tata, and Husk) are currently electrically isolated from it.[8] The three Nigerian mini grids (Mokoloki, Toto, and Wuse) will lease a part or all of the Disco's existing distribution system, whereas the two Indian mini grids will build separate new distribution systems. The case studies were researched and written in 2021 and 2022 and updated in the second half of 2023.

The five case studies are as follows:[9]

1. **The Mokoloki mini grid (Nigeria).** This electrically isolated undergrid mini grid is in the town of Mokoloki, in Nigeria's Ogun state. Its developer, Nayo Tropical Technology (Nayo Tech), agreed to lease existing distribution facilities of the Ibadan Electricity Distribution Company (IBEDC) but found it necessary to replace about 95 percent of those existing facilities. The mini grid—which involved a tripartite agreement between IBEDC (the local Disco), the local community, and the mini grid developer as the principal contractual document—became operational in February 2020. At commissioning, Mokoloki had a population of over 1,100. The mini grid was expected to become interconnected with IBEDC and make bulk purchases from the Disco sometime in the second half of 2023; however, this had not yet happened as of early December. Interconnection was delayed because IBEDC went into receivership in 2022. The mini grid's developer now has to negotiate the terms of an interconnection with a new management team.
2. **The Toto mini grid (Nigeria).** This operating interconnected mini grid is located in the town of Toto, in the service area of the Abuja Electricity Distribution Company (AEDC). The mini grid's developer, PowerGen Renewable, expects to receive electricity for 6 hours every evening from AEDC, allowing it to serve 1,700–2,000 residential and commercial customers. PowerGen plans to invest about 25 percent of the US$2 million investment (that is, US$500,000) in rehabilitating and expanding AEDC's existing distribution grid so that it can serve a customer base that is expected to grow over the mini grid's 20-year permit period.
3. **The Wuse market mini grid (Nigeria).** This interconnected mini grid in Abuja (the federal capital of Nigeria) was built to serve owners of shops and stalls in a large urban market. As part of its Energizing Economies Initiative, Nigeria's Rural Electrification Agency conducted energy audits of the market and helped select the mini grid developer Green Village Electricity (GVE), which is developing this mini grid. When it becomes fully operational, the mini grid is expected to replace the more than 3,000 small diesel generators operated by the market's merchants. During the 20-year term of the tripartite agreement between AEDC (the Disco), GVE (the mini grid owner and operator), and the Wuse Market Shop Owners Association, GVE will be the designated supplier to all shop and stall owners. GVE has AEDC's firm commitment that it will sell GVE 7 hours of electricity every night. It is estimated that about 300 other urban marketplaces could be served by similar interconnected mini grids elsewhere in Nigeria.
4. **Tata Power Renewable Microgrid (India).** In November 2019, Tata Power, India's largest power company, announced an initiative to build 10,000 microgrids in towns and villages already served by a main grid–connected Disco. Tata's service is more reliable than the local Disco's, using a 50-kilowatt (kW) standard generation package that can be deployed in multiple units for larger sites. To increase demand, the company helps customers obtain financing for appliances and machinery for productive uses. By the end of June 2023, Tata had installed and was operating 200 mini grids, and it is now exploring using biogas generators to replace more expensive diesel-fired generation and battery storage.

5. **Husk Power Systems (India and Nigeria).** Husk operates 200 non-interconnected mini grids serving more than 5,000 microenterprises in India and Nigeria. For its service, the company uses a standard modular supply system consisting of photovoltaic (PV) panels, lead-acid batteries, and biomass gasifiers. The biomass gasifiers reduce the need for backup diesel generators. Most of Husk's customers are served on a prepaid basis. In November 2021, Husk began operations at six non-interconnected mini grids in Nigeria's Nasarawa state and is exploring the possibility of building interconnected mini grids in Nigeria.

Any developer wishing to build a mini grid in an undergrid area must make two key decisions. The first is whether it should lease some or all of the Disco's existing distribution lines or build an entirely new and separate distribution system. If the developer opts to use and expand the Disco's existing distribution facilities, the second decision is whether the Disco's existing lines will continue to be electrically connected to the main grid (so that the mini grid can buy power from or sell power to the Disco or other entities connected to the main grid). Table 2.2 lists the decisions made in the five case study projects.

All Discos in Nigeria are privately owned, whereas most in India are state owned. Privately owned Discos, which are driven by the Discos' need to earn a profit on investments, generally have stronger incentives to experiment with interconnected mini grids than publicly owned Discos.

Another difference between the two settings is that Indian state regulatory systems discourage undergrid mini grids from interconnecting to local Discos. Mini grids are essentially deregulated if they remain non-interconnected and run the risk of becoming heavily regulated if they interconnect. In contrast, Nigerian national mini grid regulations encourage interconnection with local Discos, aiming for mutually beneficial outcomes for the Discos as well as the mini grids.

Interconnected mini grids are still in early stages of development. Only the Wuse market and Toto mini grids are operating as interconnected mini grids (Mokoloki appears to be very close to interconnecting). The other case studies are either isolated or still in the proposal stage for interconnection. Full information is not always publicly available, because owners/operators of the interconnected mini grids and the Discos to which they are connected are understandably reluctant to release commercially sensitive information that could hurt them in negotiations for future projects.

TABLE 2.2 Features of the mini grids in the case studies

CASE STUDY	SERVICE AREA	COUNTRY	TYPE OF UNDERGRID MINI GRID	MAKES BULK ELECTRICITY PURCHASES FROM DISCO	LEASES SOME OR ALL EXISTING DISTRIBUTION FACILITIES
Mokoloki	Rural town	Nigeria	Non-interconnected	No	Yes
Toto	Rural town	Nigeria	Interconnected	Yes	Yes
Wuse	Urban market	Nigeria	Interconnected	Yes	Yes
Tata	Rural town/village	India	Non-interconnected	No	No
Husk	Rural town/village	India	Non-interconnected	No	No

Source: Original table compiled for this publication.
Note: Disco = distribution company.

CASE 1: THE MOKOLOKI MINI GRID PROJECT (NIGERIA)

The Mokoloki mini grid project is Nigeria's first privately owned mini grid in an undergrid community (photo 2.1).[10] The project is located in the village of Mokoloki in the western state of Ogun. The village has a population of about 1,140 and is located on a heavily traveled main road connecting Ibadan and Lagos, giving it some attributes of a peri-urban area.

The Mokoloki-based mini grid is currently non-interconnected, with the possibility of becoming electrically interconnected at a later date. The grid initially had about 200 customers when it became operational in February 2020. As of June 9, 2023, it was serving 335 customers (260 residential customers, 45 commercial customers, 15 productive-use customers, and 15 public institutions).[11] Although commercial and productive-use customers represent only about 10 percent of the grid's customers, they contribute over 50 percent of the total revenue.

Before the mini grid became operational, Mokoloki was served by IBEDC, which catered to only 90 customers in the community when the mini grid was handed over. According to the villagers, IBEDC provided an unsatisfactory service, typically for no more than 5 hours per day (17–21 percent availability) and often only in the middle of the night. Many villagers had installed backup diesel-fired generators, which were noisy, expensive, inefficient, and dirty.[12] Meanwhile, the mini grid has operated with 92–95 percent availability since becoming operational.

Investments by the mini grid developer

The mini grid's developer and operator, Nayo Tech (www.nayotechnology.com), invested in both generation and distribution. For generation and storage,

PHOTO 2.1

Solar arrays, battery, power electronics, and mini grid office, Mokoloki, Nigeria

Source: ©Nayo Tropical Technology. Used with permission; further permission required for reuse.
Note: The power electronics are located inside the shipping container.

it purchased and installed a 100-kilowatt-peak (kWp) solar PV array, a 192-kilowatt-hour (kWh) lead-acid battery, and an 88 kW diesel generator. In June 2023, the battery was upgraded to 317 kWh.

Nayo Tech made major distribution-focused investments, which replaced about 95 percent of IBEDC's 35-year-old wooden poles and small-gauge service wires with concrete poles and larger-gauge service wires. This action was necessitated by Nayo Tech's written commitment to the village to provide a high-reliability service.

The project's initial capital cost was US$420,000; when it proposed the project, Nayo Tech expected to receive in-kind grants from the German Agency for International Cooperation (GIZ) that would cover about 45 percent of its capital expenses (CAPEX). According to Nayo Tech, the GIZ grants never materialized because GIZ determined that its Interconnected Mini-grid Acceleration Scheme (IMAS) would be more appropriate for funding larger interconnected mini grids (refer to appendix C for a description of the scheme). Because capital grants from Nigerian government agencies or donors were not made available in a timely way, Nayo Tech made the entire investment with its own equity. Further, the CrossBoundary Innovation Lab supported Nayo Tech in implementing a program to increase daytime consumption by five commercial customers, including retrofitting of motors to electricity and facilitating the purchase of an ice-making machine.

Nayo Tech pays IBEDC a fixed annual system usage fee, which is best thought of as a payment for the right to take over as the village's electricity supplier for a specified period rather than as a rental fee for existing distribution facilities, given the extensive distribution replacements and upgrades done by the company. When IBEDC and Nayo Tech negotiated the usage fee (a Distribution Use of System [DUOS] charge under Nigerian Electricity Regulatory Commission [NERC] regulation), the fee level was influenced by how much of the existing distribution system had to be replaced as well as the potential for Nayo Tech to increase retail sales. It has been reported that future mini grid projects in the IBEDC franchise area will probably pay IBEDC a DUOS fee tied to the number of kWh sold to its customers rather than an annual fixed amount.

Smart meters

The Mokoloki mini grid provides a pay-as-you-go smart meter to every customer.[13] As it deploys meters, Nayo Tech is gathering data on customer service, hardware reliability, and integration flexibility. Smart meters are used to collect revenues on a prepaid basis, as well as time-stamped consumption and power quality data. When fully operational, these meters will allow for remote diagnosis of technical issues, detection of electricity theft, and development of granular data for the company to plan its expansion in the village and elsewhere. Besides these monitoring functions, the meters can be used to remotely turn off electricity to individual customers.

Interconnection

The Mokoloki mini grid began operation as an electrically isolated mini grid. Nayo Tech's tripartite agreement with IBEDC and the Mokoloki community left open the option to reconnect and share power in the future (RMI 2020). From the mini grid's perspective, the decision to interconnect will depend on the expected availability of IBEDC-supplied electricity and its price. From IBEDC's perspective, this decision will depend on whether it will need to make additional investments; the likely volume of wholesale electricity sales to the mini grid; the price that can be charged for its wholesale sales; and the penalties, if any, IBEDC would be required to pay to Nayo Tech if it fails to supply according to the agreement.

Nayo Tech anticipated that it would interconnect with IBEDC shortly after the Mokoloki mini grid began commercial operations in 2020. It expected that the energized interconnection would allow it to purchase 2 to 4 hours of lower-cost electricity from the Disco on most days. Regular bulk purchases from IBEDC would allow Nayo Tech to reduce the electricity generated by its on-site diesel generators as well as the size of the installed capacity of on-site storage batteries. As of December 2023, the interconnection had not yet occurred. IBEDC is in receivership, and its new management has yet to decide on the portion of the upgrade costs that it will cover and the wholesale sales commitments it is willing to make. The mini grid thus continues to operate in a non-interconnected mode and has been forced to generate more electricity from expensive diesel fuel than it had projected.

A 2023 grant from the Global Energy Alliance for People and Planet will provide US$60,000–US$65,000 to create a workable interconnection between IBEDC and the mini grid. The grant will cover the cost of a 500-kilovolt-ampere (kVA) transformer to accommodate current loads and expected 5-year load growth, a 300 kVA voltage stabilizer, repair work on distribution cross-arms and cables (some of which were vandalized), and the clearing of trees and bushes around transmission lines. The interconnection was unlikely to be made without this grant.

In anticipation of an interconnection, Nayo Tech is negotiating a tariff for the electricity that IBEDC would supply. It is also seeking assurances from IBEDC that the electricity it supplies will be available for at least 8 hours between 6 pm and 6 am (dusk to dawn). The electricity in a nearby subfeeder has historically been available for 6 hours per day, on average; however, as of December 2023, it remained unclear what portion of that time is reliably between dusk and dawn.

Nayo Tech is pursuing two other interconnected mini grids. The first is a solar mini grid (800 kWp of solar PV, a 1,350 kWh battery, and a 500 kW inverter) that would be an interconnected mini grid within the IBEDC franchise area in Okeoyi village in Kwara state. All distribution cables and poles (financed through a GIZ grant) had been delivered for this mini grid as of January 2023. The construction of a powerhouse is awaiting the signing of a tripartite agreement; when built, the mini grid will serve about 2,500 connections, seven times more than Mokoloki's. A second interconnected mini grid (1,200 kWp, 2-megawatt-hour [MWh] battery, and 900 kW inverter) with 4,500 possible connections is in the planning stage in Niger state in the AEDC franchise area.

The business model

The key legal document for the project is a tripartite agreement between IBEDC, Nayo Tech, and the Mokoloki community. Because Mokoloki was deemed a pilot project, the three parties agreed to only a 10-year term. Future mini grid projects will likely have terms of 15–20 years.

The key legal document for the project is a tripartite agreement between IBEDC, Nayo Tech, and the Mokoloki community.

The Rocky Mountain Institute (RMI) was the principal advisor to all three parties. The tripartite agreement spells out the rights and obligations of each. The agreement is based on a model tripartite agreement for interconnected mini grids that NERC included as an annex to its 2016 mini grid regulations

(NERC 2016, annex 11). That agreement was developed for interconnected mini grids, so it was modified slightly to reflect the fact that the Mokoloki mini grid will operate in an entirely electrically isolated or islanded mode, at least initially (refer to chapter 5 for a discussion of islanding). Because the Mokoloki project was financed entirely with Nayo Tech's own equity, it does not provide a test of whether similar tripartite agreements could support external commercial financing of mini grid projects.

Under the Mokoloki tripartite agreement, Nayo Tech is responsible for maintaining all generation and distribution, in addition to handling metering, billing, and collections. Customer complaints go to Nayo Tech first and are turned over to IBEDC if they cannot be resolved. Customers have the option of taking their complaints to NERC if IBEDC does not resolve them.

Nayo Tech is responsible for building all generation and distribution upgrades over the life of the agreement. The upgrades will be handed over to IBEDC at the end of that 10-year period. IBEDC will continue to own the distribution assets provided to Nayo Tech for the project's duration. At project termination, IBEDC will also own any new distribution assets built by Nayo Tech. IBEDC will compensate Nayo Tech for the depreciated value of any assets installed by Nayo Tech during the 10-year period. In effect, Nayo Tech will be a fully functioning microutility operating as a sublicensee to IBEDC during the agreement's 10-year term.

Mini grid and Disco retail tariffs

In September 2020, NERC approved a metered, non-time-differentiated tariff of 140 Nigerian naira (N) (US$0.339) for Nayo Tech's residential customers, and time-differentiated tariffs of N120 (US$0.291)/kWh between 9 am and 4 pm and N140 (US$0.339)/kWh outside this period for commercial customers.[14] Nayo Tech's time-differentiated tariffs reflect a typical solar mini grid's cost structure, in which it is less expensive to produce electricity in the middle of the day using a mini grid's solar panels than at night. Supplying electricity at night requires discharging the mini grid's batteries or running the diesel generator unless electricity becomes available through an interconnection with IBEDC (refer to chapter 4 for an estimate of the levelized cost of drawing down electricity that has been stored in a battery).

Nayo Tech's time-differentiated tariffs reflect a typical solar mini grid's cost structure, in which it is less expensive to produce electricity in the middle of the day using a mini grid's solar panels than at night.

IBEDC's NERC-approved tariffs were N24.97(US$0.0605)/kWh when its Mokoloki customers were receiving 4–5 hours of service per day. NERC might approve higher tariffs if IBEDC provides substantially higher levels of service (refer to box 2.1).

To set the tariffs for the mini grid, NERC used a formula for both isolated and interconnected mini grids called the multiyear tariff order, or MYTO (NERC 2021). The tariff is calculated for each proposed mini grid based on CAPEX and operating expense (OPEX) data submitted by the developer through an online portal on NERC's website. Nayo Tech submitted detailed information on the project's capital costs, operation and maintenance costs, DUOS charges (leasing payments for the use of IBEDC's existing distribution system), and Nayo Tech's proposed capital structure (100 percent equity). NERC used Nayo Tech's physical and financial inputs to calculate the maximum allowed tariff. Under the MYTO tariff-setting formula, Nayo Tech could have charged a tariff of N174/kWh (based on the exchange rate prevailing in 2019), but it opted to charge the lower rate of N140 (US$0.339)/kWh to make the tariff more affordable to its customers in Mokoloki.

BOX 2.1

NERC-approved tariffs for IBEDC and other Nigerian Discos

In late 2020, the Nigerian Electricity Regulatory Commission (NERC) approved a set of new retail tariffs for the Ibadan Electricity Distribution Company (IBEDC) and Nigeria's other 10 distribution companies (Discos). These tariffs, which are considerably higher than the previous ones, are tied to the hours of service provided and are described as service-based tariffs.

The new NERC-approved tariffs specify five service bands tied to the hours for which a Disco commits to supplying electricity. Service Band A requires IBEDC to supply its customers electricity for at least 20 hours daily. Because Nayo Tropical Technology supplies electricity to Mokoloki mini grid customers for close to 24 hours a day, Service Band A is the most relevant tariff class for comparing IBEDC's tariffs with Mokoloki's. The permitted price per kilowatt-hour under IBEDC's Service Band A is 62.33 Nigerian naira (N) (US$0.151). The NERC-approved tariffs for Nayo Tropical Technology are higher (N120–N140 [US$0.291– US$0.339]). However, this is a hypothetical comparison because it is unlikely that IBEDC would ever be able to supply electricity to Mokoloki for 20 hours a day given the state of its distribution network and power availability.

If an agreement on interconnection with IBEDC is reached, Nayo Tech will submit a new tariff approval request to NERC with all relevant cost information, including the wholesale tariff for electricity that Nayo Tech plans to purchase from IBEDC.

Nigeria's current mini grid regulations make no provision for automatic adjustment of tariffs for cost increases that are beyond the control of a mini grid operator (for example, changes in global oil prices and general inflation). In contrast, the tariff-setting system for Nigeria's 11 Discos provides for semi-automatic tariff adjustment for cost factors deemed to be beyond the Disco's control.

Load growth and system upgrade

Mokoloki's sales have grown significantly since the mini grid became operational in February 2020. In 2021, the average total monthly sales were 5,300–6,000 kWh (18 percent generated from diesel generation), serving about 210 customers, representing an average monthly consumption of 25–28 kWh per customer. The average total monthly sales in 2023 rose to 9,900 kWh, although average monthly consumption was still about 28 kWh for each of 345 customers. The average consumption of residential customers is much lower (6–7 kWh per month). Consumption is lower during the rainy months (April–October) and higher during dry months (November–March). Mokoloki's consumption of 28 kWh per month is higher than the reported average monthly consumption of 6.24 kWh for 288 privately owned mini grids in 12 African countries (AMDA 2022). Nayo Tech also reports that Mokoloki's "average revenue per user is twice that of a comparable off-grid site in Nigeria" (Nayo Tropical Technology 2022).

In response to the increased load and with funding secured by RMI from the Dutch Postcode Lottery proceeds, the system was upgraded with a more powerful inverter and with a battery capacity expanded from 192 kWh to 317 kWh. The expanded battery capacity will improve the Mokoloki mini grid's ability to provide reliable power, especially in the monsoon months of April through August, when solar production is low and the mini grid's battery could charge from available electricity from IBEDC. The new inverter is direct current–coupled and will increase the use of electricity generated from the mini grid's solar array.[15] Commissioning of these upgrades was completed on June 5, 2023.

The grant funding was structured as a community profit-sharing arrangement, in which a community association has a minority (about 10 percent) share in the project. Under the community minority ownership arrangement, the community will receive 10 percent of future mini grid profits (revenues minus expenses). Nayo Tech expects that the community will have voting rights on most issues other than tariffs. The legal framework for the community association is still under development, including its code of conduct and how proceeds can be used.

The grant funding was structured as a community profit-sharing arrangement in which a community association has a minority (about 10 percent) share in the project. Under the community minority ownership arrangement, the community will receive 10 percent of future mini grid profits (revenues minus expenses).

Rising diesel prices and financial challenges

Notwithstanding the system upgrade and increased sales, Nayo Tech's finances have been challenged by the rising price of diesel fuel. In January 2022, the price of diesel fuel rose from N250 (US$0.605)/liter to N370 (US$0.895)/liter, increasing the cost of operating the mini grid's diesel generator. After several months of negotiation, Nayo Tech reached an agreement with the community to temporarily increase the retail tariff from the NERC-approved N140/kWh to N162 (US$0.35 at June 2023 exchange rates)/kWh, with an additional monthly fixed service charge of N500 (US$1.08). Even this tariff increase was insufficient when diesel prices jumped from N370 (US$0.896)/liter to N900 (US$2.179)/liter in July 2022 and stayed at similar levels throughout 2023. The N162 (US$0.35)/kWh retail tariff is sufficient to cover up to 3 hours of diesel-based electricity per day (necessary only during the rainy season) in addition to the solar-generated electricity. Subsequently, to reduce financial losses due to high diesel-related expenses, the mini grid has temporarily reduced availability to about 60 percent.

Financial benefit for customers

At first glance, the mini grid's arrival appears to have hurt rather than benefited Mokoloki's electricity consumers. Nayo Tech charges the mini grid's customers a tariff that is over five times the tariff they had been paying to IBEDC. But this simple comparison of tariffs ignores several key factors:

- Households served by IBEDC were not metered and may have received less electricity than they were billed for (underestimated billing).
- IBEDC provided only 4–5 hours of electricity per day.
- When IBEDC power was not available, customers either used their own diesel generators or went without electricity.
- In contrast, electricity from Nayo Tech was available at least 22 hours a day (with nonavailable hours typically between midnight and 5 am), although availability has decreased to about 14 hours per day in the wake of high diesel prices.

RMI, the neutral advisor to IBEDC, Nayo Tech, and the villagers, estimates that the village would save about N25 (US$0.061)/kWh on average compared with its pre–mini grid cost of N178 (US$0.431)/kWh.

Financial benefits for IBEDC

IBEDC derives three potential financial benefits from transferring its supply obligations to the Nayo Tech mini grid:

1. It will receive a new revenue stream, in the form of fixed monthly payments from Nayo Tech for granting it the right to provide electricity in Mokoloki (the DUOS fee).
2. It will staunch the financial losses it incurs serving Mokoloki.
3. It will enjoy bulk power sales revenues if Nayo Tech interconnects to the grid and begins purchasing bulk electricity from IBEDC in the future.

IBEDC can capture the first two benefits with very little effort by collecting the DUOS fee and turning over its customers to Nayo, in turn eliminating the financial losses it previously incurred in serving the community. The third benefit may not materialize soon, because IBEDC is not likely to have a financial incentive to energize the feeder line into Mokoloki, given the community's location on the IBEDC system.

CASE 2: THE TOTO INTERCONNECTED MINI GRID (NIGERIA)

The Toto project, which will be one of Nigeria's first privately owned and operated interconnected mini grids in an underserved area, reached financial closure with its project lender at the end of 2021, meeting all conditions required to draw down on the funding.[16] This milestone enabled the developer, PowerGen, to fully shift to project implementation, complete equipment procurement, and begin construction in May 2022. Soft commissioning and project testing began in April 2023, with power provided 24 hours a day, 7 days a week (24/7). Subsequently the mini grid's coverage area was expanded beyond the project's initial scope, interconnection was achieved, and formal commissioning took place on November 9, 2023.

The project is located in the town of Toto, a peri-urban area in Nasarawa state, 195 kilometers south of Nigeria's Federal Capital Territory. Toto lies within AEDC's licensed service area, but AEDC has not been able to provide any service to it for many years owing to weaknesses in its distribution infrastructure and the lack of electricity meters to improve billing and collection.

PowerGen is designing the Toto interconnected mini grid (refer to photo 2.2) to make electricity available for customers 24 hours a day. It has sized the mini grid, which includes 352 kWp of solar PV panels and 972 kWh of lithium-ion battery capacity, to supply power for 18 hours a day. Once interconnected, its internally generated power supply will be supplemented with electricity purchased from AEDC for approximately 6 hours at night and with electricity generated as backup by its own diesel generator, which has a rated capacity of 500 kVA.

To distribute power to customers, PowerGen will lease AEDC's existing distribution system in Toto. It will also invest about US$500,000 to refurbish AEDC's distribution system there and install a power transformer at the interconnection point that connects the town to the rest of the AEDC distribution system (refer to photo 2.3). PowerGen estimates that its investments in distribution upgrades will equal about 25 percent of its total capital investment of US$2 million in the Toto mini grid.

PHOTO 2.2

Interconnected mini grid, Toto, Nigeria

Source: ©PowerGen Renewable. Used with permission; further permission required for reuse.

PHOTO 2.3

Installation of new distribution poles in Toto, Nigeria, by PowerGen Renewable

Source: ©PowerGen Renewable. Used with permission; further permission required for reuse.
Note: The wooden poles in the background are part of the Abuja Electricity Distribution Company's original distribution network.

Toto is a peri-urban area, with a much larger customer base than an isolated rural mini grid, which might typically serve 200–400 customers. PowerGen currently anticipates that the interconnected mini grid will serve 2,000 households, 141 commercial users, 18 productive users, and 45 public users. Its larger potential customer base offers more opportunities for demand growth, especially from commercial customers, whose electricity demand is likely to be concentrated during daylight hours, improving the project's load factor and reducing the average cost of production (refer to chapter 4 for an estimate of how the load factor affects the unit costs of production for an interconnected mini grid).

Rental charge for use of existing distribution facilities

Like the Mokoloki and Wuse market mini grids, the Toto mini grid project will lease some existing distribution facilities from AEDC. A DUOS fee can be structured as a flat monthly payment (as in Mokoloki) or a per-kWh payment based on the volume of electricity that the mini grid operator sells to end-use customers in a specified period with its own power supply (as in Toto and Wuse). The DUOS fee is based on an estimate of AEDC's monthly carrying charges on the undepreciated value of the distribution system assets for the Disco. PowerGen views the DUOS fee as a payment for the right to use AEDC's existing infrastructure in Toto.

If AEDC decides to take back the Toto service area at the end of the 20-year agreement, it will take ownership of all distribution system improvements made by PowerGen, with PowerGen receiving compensation equal to the depreciated value of the improvements it made.

Following ground-level assessments, the PowerGen team found that the 415-volt (V) (low-voltage) distribution system needed to be completely replaced, and that about 90 percent of the 11-kilovolt (kV) (medium-voltage) system also needed to be replaced. In view of the substantial investment required to expand and upgrade the network, PowerGen and AEDC agreed that PowerGen should receive a credit on the DUOS fee to help it recover its capital investment in the network infrastructure. If AEDC decides to take back the Toto service area at the end of the 20-year agreement, it will take ownership of all distribution system improvements made by PowerGen, with PowerGen receiving compensation equal to the depreciated value of the improvements it made.

Electricity purchases from AEDC

The interconnection between the mini grid and the rest of AEDC's distribution system will allow the mini grid to purchase electricity from AEDC. Under the terms of the tripartite agreement, PowerGen will purchase electricity from AEDC during "priority hours" and an "availability period." Priority hours will initially be 6 hours within a 7-hour window from 6 pm to 1 am. The availability period will be from 1 am to 4 am. During priority hours, AEDC is required to supply power and PowerGen is required to take electricity supply from the grid to the extent required to meet the total electricity demand of PowerGen's customers in Toto. During the availability period, PowerGen is required to supply at least 25 percent of its customer demand using AEDC-supplied grid power. The price for electricity is the same in the two periods. Based on an initial forecast, AEDC will be providing PowerGen with 30–40 MWh a month.

Electricity purchases from AEDC will reduce PowerGen's operating costs and initial project costs. PowerGen will use the purchased power to serve its customers during evening and nighttime hours and, if necessary, to charge the mini grid's batteries if they were not fully charged during daytime hours by the solar PV panels. Without these purchases, PowerGen would have to rely on its battery energy storage solution, its on-site diesel generator, or both to supply electricity to its household and commercial customers. Drawing down electricity that had been stored in batteries would cost approximately US$0.30–US$0.50/kWh depending on use. In 2023, electricity production using a diesel generator cost US$0.40–US$0.60/kWh. The price PowerGen will pay for its electricity purchase from AEDC is regulated. For the Toto project, the price would have been N67.70 (US$0.164) had the mini grid been operational during the first 6 months of 2021.[17] Given the cost differences between the three supply sources (AEDC power, battery storage, and backup diesel generator), PowerGen should always have a strong economic incentive to prioritize power purchased from AEDC except over daytime solar-generated electricity.

PowerGen estimates that the availability of 6 hours of robust grid supply purchased from AEDC will help lower its initial capital costs by an estimated 15–20 percent by letting it install less battery capacity. PowerGen estimates that lower CAPEX and OPEX will reduce its levelized cost of electricity by about 10 percent.

PowerGen estimates that the availability of 6 hours of robust grid supply purchased from AEDC will help lower its initial capital costs by an estimated 15–20 percent by letting it install less battery capacity.

Compensation for the Disco's failure to fulfill its supply commitment

The biggest risk for PowerGen—or any interconnected mini grid developer—is a possibility that the local Disco or another main grid supplier may fail to fulfill its promised supply commitment. If this happens for the Toto project, then the mini grid's evening supply costs could increase from the AEDC rate of US$0.164/kWh for grid-supplied electricity to US$0.40–US$0.60/kWh (the estimated cost of generating the electricity with the on-site diesel generator). The mini grid operator will thus want compensation if the Disco fails to fulfill its supply commitment. From the mini grid operator's perspective, the level of compensation should be set at the difference between the cost per kWh of generating the electricity with its on-site diesel generator and the price it would have paid had the same amount of electricity been purchased from the Disco.

Two compensation mechanisms have been discussed. In one, compensation for nonsupply is netted out from the DUOS charge (the Wuse interconnected mini grid case uses this mechanism). This compensation mechanism will not work for the Toto project, because PowerGen's investment in major distribution upgrades eliminates any DUOS charges for the project for a number of years.

A second mechanism is to subtract the compensation for nonsupply from Toto's payments for power purchases from AEDC until the shortfall in compensation is fully paid. This mechanism poses a different risk. If the Disco fails to supply electricity during priority hours, the accumulated compensation payments might exceed the billed amounts for power purchased in the following months. AEDC would thus find itself in the difficult position of purchasing upstream bulk electricity but not receiving any payment when it resells this electricity downstream to Toto (that is, incurring a cost for which there is little or no compensation). PowerGen and AEDC have agreed to cap the amount that may be deducted as compensation from Toto's payments for power purchases. In the extreme case, the contract could be terminated.

Retail tariffs

PowerGen proposes to charge a uniform tariff for all users at night and a discounted tariff for its commercial customers during daytime hours (9 am–5 pm). The exact retail tariffs will not be known until NERC approves PowerGen's proposed tariffs.

In the tripartite agreement (described in a later subsection), PowerGen commits to a 95 percent level of availability across 24 hours of power service. For a comparable level of service, AEDC received NERC's approval to charge a tariff of N67.70 (US$0.164) over the first 6 months of 2021. The NERC-approved tariff for the mini grid's commercial customers in the Toto community is likely to be two to three times AEDC's comparable tariff for its commercial customers for a similar 20 daily hours of service. This comparison is not meaningful, however, because on its own AEDC is unlikely to be able to provide 20 hours of daily

In the tripartite agreement . . ., PowerGen commits to a 95 percent level of availability across 24 hours of power service.

service in Toto using its current distribution system—and, given its limited CAPEX budget, it is likely to give higher priority to using its CAPEX funds to improve service for customers in its franchise area outside of Toto.

PowerGen's lower proposed daytime tariff for commercial customers is driven by the low cost of electricity production from solar PV panels during the daytime. The cost of nighttime electricity purchases from AEDC is also low, although the reliability of this supply source is unknown. PowerGen's retail tariffs will be higher at night if batteries or backup diesel generators have to be used. If nighttime electricity from AEDC is consistently available during priority and availability periods (reducing the need for battery-supplied electricity and electricity produced by a diesel generator), then PowerGen may reduce the nighttime tariff to reflect the lower cost of energy due to reduced use of the diesel generator.

This approach (lower tariffs for commercial customers during daytime hours) is similar to the tariff structure of Nayo Tech in the Mokoloki project. By reducing commercial tariffs during daylight hours, PowerGen also hopes to increase its overall sales, which would reduce its unit costs of production.

In February 2022, NERC issued a permit to proceed with the development of the Toto interconnected mini grid project. The approved tariffs are N150 (US$0.363)/kWh for businesses and commercial operations between 9 am and 5 pm and N180 (US$0.436)/kWh for residential customers, as captured in the tripartite agreement.

Demand stimulation

To increase sales and revenues in Toto and other mini grid projects, PowerGen will have to make two operational decisions on how to stimulate demand. The first is whether it should try to increase its customers' consumption through efforts by its own staff or by hiring a third party to handle marketing and financing. The second is whether it should focus on increasing demand from commercial and agricultural customers (for example, welding, milling, and water pumping), from residential customers, or from both. In general, mini grids have stronger incentives to increase commercial and agricultural loads, because C&I customers are more likely than residential customers to respond and because demand increases will likely be during daytime, when operating costs are lower.

The tripartite agreement

For the Toto project, a tripartite agreement is the primary contractual agreement between AEDC, PowerGen, and the Toto community.[18] This agreement is based on a model tripartite agreement that NERC included as an annex to its 2016 mini grid regulations (NERC 2016). It is likely that similar terms will appear in the tripartite agreements of other interconnected mini grids in Nigeria.

The tripartite agreement can be thought of as an example of regulatory delegation or regulation by contract.

The tripartite agreement can be thought of as an example of regulatory delegation or regulation by contract.[19] The underlying presumption is that the three parties are in a better position than the national regulator to identify their specific commercial and technical needs. NERC must approve the agreement when PowerGen applies for a permit and for approval of its proposed retail tariffs.

The tripartite agreement sets out the terms under which the Toto mini grid will connect to AEDC's distribution network and operate as an interconnected mini grid, supplying electricity to the Toto community, including the following:

- Commencement and term
- Right to use the distribution network (lease of distribution assets)
- Duties and obligations of the three parties
- Ownership of new installations
- Connection of generation assets to the distribution network and expansion of the distribution network
- Sale of electricity between the mini grid operator and the interconnected community
- Tariffs.

Smart meters

The Toto mini grid will use pole-mounted, prepaid smart meters certified by the Nigerian Electricity Management Service Agency for both its single- and three-phase customers. To top up meters, customers can pay cash to a local agent, who updates the meters remotely. Agents purchase bulk credits on a prepaid basis from the operator via bank deposit. Customers will soon be able to pay PowerGen directly through unstructured supplementary service data, a data system universally available on cell phones that allows second generation or text message–based interactions with the service provider by typing in a code.

Smart meters monitor voltage at each customer's premises. This monitoring can be useful in detecting and resolving technical issues such as damaged wires or circuits that need to be reconductored to accommodate increasing load. Smart meters can also help detect electricity theft by aggregating kWh meter readings among a group of customers and comparing that aggregate to a totalizing meter upstream of the customers. Data are collected every 15 minutes, allowing PowerGen to understand the evolution of customer demand almost in real time.

The meters will be owned by PowerGen and included as part of its CAPEX cost, which will be recouped through electricity bills over time.[20] Meters cost US$30–US$40 each for single-phase customers and US$80–US$100 each for three-phase customers. PowerGen will pay a monthly meter service fee to the meter technology provider for the ongoing use of its software platform.

Financing and ownership

Most mini grids require initial financing for project development and construction. PowerGen estimates that its project development costs will equal about 20–30 percent of the project costs. The project development costs include surveys, technical due diligence, engineering, community and customer engagement, regulatory engagement on national and state levels, environmental permitting, and capital raising. The project development costs will probably go down as PowerGen gains more experience with interconnected mini grids.

Like Nayo Tech for the Mokoloki project, PowerGen could fund project development with its own internal resources. However, it is unlikely that many other Nigerian mini grid developers will have the capability to self-finance. The Distributed Energy Solutions Strategy for AEDC has been proposed to support the scale-up of such projects through the provision of financing (refer to box 2.2).

BOX 2.2

Interconnected mini grids and the DESSA initiative

The Toto project in Nigeria is one of the first projects of the Abuja Electricity Distribution Company (AEDC) under the Distributed Energy Solutions Strategy for AEDC (DESSA)—a project development, financing, and management initiative proposed by AEDC to support the deployment of decentralized energy solutions in combination with grid supply to address funding and service-quality gaps within its franchise area. DESSA is part of a wider integrated distribution framework intended to align a utility's core business with distributed energy resources. Like mini grids, distributed energy resources can augment grid supply and investments in unserved and underserved areas and enable distribution companies to meet their electricity supply and access mandates in a more cost-effective manner.

DESSA aims to support the scale-up of interconnected mini grids across AEDC's franchise by

- Identifying a pipeline of sites for mini grid developers for complementary interconnected mini grid projects,
- Providing support for initial project development, and
- Helping mobilize a pool of capital from third-party financiers to invest in these projects.

DESSA facilitated the development of the Wuse market and Toto interconnected mini grids. In its pipeline are 17 other projects to help develop over 80 megawatts of decentralized clean energy supporting over 50,000 connections.

Most mini grid developers hope for a debt-to-equity ratio of about 80:20. This high degree of leverage is difficult to achieve for a pilot project like Toto. In the future, however, it would be a significant accomplishment if projects like Toto could achieve a 60:40 debt-equity split.

In October 2021, the Rural Electrification Agency announced that interconnected mini grids would be eligible for performance-based grants[21] funded by the World Bank's Nigeria Electrification Project; at the same time, it raised the amount of performance-based grants from US$350 to US$600 per connection. The grants were given in naira at the official exchange rate and not in US dollars. However, the full US$600 was not available when the developer had to purchase imported equipment (for example, PV panels, inverters, and meters). When the developer needed to acquire dollars to pay for imports, the dollars were not available at the official exchange rate. Instead, the developer had to convert naira into dollars at a much less favorable open market exchange rate.

As a result, Nigerian developers received the naira per-customer grants with a lesser estimated effective dollar buying power of US$300–US$420. Thus, in October 2023 when the grant amount was changed to US$450 but given directly in US dollars, there was little or no loss in effective buying power for mini grid developers (refer to appendix F for a description of these changes). Subsequent shorthand references in this book to the "US$600 performance-based subsidy" refer to the nominal value of the grant at the official exchange rate, but it should be recognized that the actual dollar amount available for imports was considerably lower. To date, Toto has received 1,600 grants for connections at US$600 per connection in naira. Any future connections will be at the new US$450 amount.

Like all mini grid developers in Nigeria, PowerGen will have to decide whether to use the extra grant proceeds to reduce retail tariffs, to improve returns for investors, or a combination of the two.

Like all mini grid developers in Nigeria, PowerGen will have to decide whether to use the extra grant proceeds to reduce retail tariffs, to improve returns for investors, or to achieve a combination of the two. PowerGen intends to create a special purpose vehicle (SPV) to own the Toto project. An SPV would permit PowerGen to seek other equity investors for the project, reducing the size and risk exposure for its own investment. Other investors in the SPV would probably require that PowerGen retain at least a 10 percent equity interest in the SPV so that it continues to have a financial stake in the project's success after the mini grid becomes operational. The new multiowner SPV is expected to sign an operation service agreement with a PowerGen subsidiary to operate and maintain the project.

Technical design and operations

PowerGen purchased about US$20,000 of equipment needed to enable the Toto mini grid to operate in both grid-connected and islanded mode. A 33 kV–11 kV step-down transformer will connect the mini grid system to AEDC's medium-voltage power lines. The transformer is accompanied by a 33 kV isolator (high-voltage switch) and a surge arrestor (also on the 33 kV side) to protect against nearby lightning strikes. On the 11 kV side, a manual changeover switch allows Toto to switch over from AEDC power to self-generation when AEDC power is not available. A 500 kVA transformer steps down AEDC-originated electricity from 11 kV to 400 V for use at Toto's powerhouse when Toto is not self-generating. A 650 kVA step-up transformer boosts the voltage from Toto's 400 V generation output to 11 kV for distribution to the community.

PowerGen has not yet added power factor–correcting capacitors. Instead, the battery inverter has the ability to inject reactive power into the mini grid's distribution network if necessary. Following this approach, PowerGen will monitor customers' loads and will recommend power factor corrections to customers with huge inductive loads. Load monitoring will aim to target power factor corrections more precisely and reduce inefficiencies and capacity constraints that occur when the inverter performs the power injection function from the powerhouse.

CASE 3: THE WUSE MARKET INTERCONNECTED MINI GRID PROJECT (NIGERIA)

The Wuse project is an interconnected mini grid built to serve the largest urban marketplace in Abuja, the capital of Nigeria. The market has more than 2,155 shops, stalls, and storage rooms and 40 cold rooms to refrigerate food. The full project will be an integrated PV hybrid solar system with a planned final configuration of 1 megawatt-peak of solar PV, 1.2 MWh of high-efficiency lithium-ion battery storage, and a 1 MW backup diesel generator built to serve all three market sections. The mini grid developer, GVE (www.gve-group.com), also has plans to expand the battery storage capacity should demand increase.

The mini grid is in a pilot phase, with average daily sales of 2.42 kWh for each of the 20 connected customers using an installed capacity of 23 kWp solar PV and 76.8 kWh battery storage. GVE reports a 99.99 percent level of availability in the pilot phase. Similar mini grids could be installed in about 300 urban marketplaces in Nigeria.[22] Once the mini grid system is fully operational, GVE expects to supply electricity on a 24/7 basis throughout the market. The system will allow shop and stall owners to stop using more than 3,000 small petroleum and diesel generators, which are noisy, dirty, and costly to run (refer to photo 2.4) and will also allow the market to extend its closing hour from 6 pm to 9 pm.[23]

Once the mini grid system is fully operational, GVE expects to supply electricity on a 24/7 basis throughout the market. The system will allow shop and stall owners to stop using more than 3,000 small petroleum and diesel generators, which are noisy, dirty, and costly to run.

PHOTO 2.4

Noisy, polluting diesel generators at Wuse market in Abuja, Nigeria

Source: ©Arne Jacobson, Schatz Energy Research Center, California Polytechnic University, Humboldt (Cal Poly Humboldt). Used with permission; further permission required for reuse.

PHOTO 2.5

Lithium-ion batteries installed in a shipping container at Wuse market, Abuja, Nigeria

Source: ©Ifeanyi Orajaki, Managing Director, Green Village Electricity. Used with permission; further permission required for reuse.
Note: These 1.2-megawatt-hour lithium-ion batteries are installed in this ventilated 40-foot shipping container together with power conversion equipment and the mini grid's energy management system.

Although installation of the mini grid plant is complete (refer to photo 2.5), the full 1-megawatt-peak mini grid has not yet been commissioned. Interconnection of the mini grid to the AEDC 33 kV network and the commencement of full commercial operations are delayed. Demand growth at the Wuse market triggered the need for additional investment in interconnection infrastructure that was not factored into the project design and costing, leading to a dispute over which party is responsible for bearing this cost. Fortunately, GVE was able to mobilize additional funding from the Global Energy Alliance for People and Planet for this purpose, and interconnection with the AEDC network is now in progress.

The project's CAPEX is about US$2.1 million. Generation assets (for example, solar PV, batteries, and inverters) account for about US$1.37 million (about 65 percent of total CAPEX). New single- and three-phase smart meters cost about US$151,000; the introduction of a robust smart distribution automation, switching, and control infrastructure cost another US$177,000. New distribution assets and enhancement cost US$88,000 (about 4 percent of CAPEX). The distribution share of CAPEX is low because the distribution assets of AEDC, the previous retail supplier in the market, were in relatively good condition. The Wuse market project has been approved for a performance-based CAPEX grant of US$600 per connected customer from the Nigeria Electrification Project, which will substantially improve project economics.

Like most interconnected mini grid developers in Nigeria, GVE will lease the existing distribution assets of the Disco, AEDC. Initially, GVE's DUOS (leasing) payment will equal N12 (US$0.029) for every kWh GVE supplies to shop and stall operators. If GVE supplies an estimated 857,557 kWh in the first year of full operation, AEDC will collect N13 million (US$31,477) in annual DUOS charges. The DUOS payments will be tied to GVE's production of electricity from its own generators (PV panels and a diesel generator) on the WUSE mini grid. AEDC will have access to a meter that measures electricity production on the GVE system. GVE will make monthly DUOS payments to AEDC based on monthly readings on this meter. The level and structure of the DUOS rate is subject to approval by NERC.

Electricity purchased from the Disco

In addition to the electricity generated from PV panels and an on-site diesel generator, the mini grid's interconnection to AEDC at an 11 kV/415 V substation will allow GVE to purchase electricity from AEDC. Under the terms of this agreement, GVE will purchase 7 hours of grid electricity from AEDC between the priority hours of 7 am and 10 am and 4 pm and 8 pm. AEDC has an obligation to supply 2,177 MWh of electricity a year during priority hours. Between 9 pm and 7 am, AEDC can supply additional amounts of electricity if it is available and if GVE is willing to purchase it.

The price of the wholesale power that AEDC supplies to the project is considerably lower than the estimated cost of US$0.33/kWh for GVE to generate the same electricity from the mini grid's diesel generator (or an estimated US$0.34–US$0.36/kWh to draw down the electricity from the mini grid's on-site batteries; refer to appendix G for calculations of the levelized cost per kWh of electricity cycled through batteries). This wholesale price is not set by contract but rather is governed by NERC regulations, specifically AEDC's obligation to comply with the MYTO tariff-setting formula. The AEDC bulk sales tariff has increased from N36.00 (US$0.087)/kWh to N54.13 (US$0.131)/kWh since the original tripartite agreement was negotiated in October 2019. This increase will raise GVE's operating costs by an estimated 50 percent. The increase triggered negotiations between GVE and the Wuse Market Traders Association (WUMATA) over a higher retail price for shop and stall owners.

AEDC has made a firm commitment to supply electricity to GVE. If it fails to provide GVE with the agreed amount of grid-supplied electricity, GVE's DUOS payment to AEDC will be reduced by the amount of the penalty (N12 [US$0.029]) for every kWh not supplied. The penalties will be applied as a credit that will reduce GVE's monthly DUOS payment.

GVE's planned purchase of firm electricity from AEDC allows it to reduce both its up-front capital investment and its ongoing OPEX.

GVE's planned purchase of firm electricity from AEDC allows it to reduce both its up-front capital investment and its ongoing OPEX. GVE's planned purchase of main grid electricity from AEDC provides an alternative source of backup supply that allows GVE to reduce the installed capacity of its batteries. Doing so reduces GVE's up-front capital investment, which reduces its overall supply costs. The purchases also allow GVE to reduce the amount of electricity that needs to be generated from the backup diesel generator. In contrast, an electrically isolated mini grid will not have access to a lower-cost grid supply source. All things equal, an isolated mini grid therefore has higher costs and needs to charge higher tariffs than an interconnected mini grid.

The tripartite agreement

AEDC, GVE, and WUMATA signed a 20-year agreement that can be extended if all three parties agree to do so. The tripartite agreement, which NERC reviewed and approved, can be thought of as a subfranchise agreement, because GVE is assuming AEDC's full retail license obligations for the Wuse market. Under the agreement, GVE will be responsible for all retail electricity sales to the shop owners in the market. GVE also assumes responsibility for building the mini grids and operating and maintaining the on-site generation and distribution system, as well as taking over metering, billing, and collections for retail customers in the market. GVE will use prepaid smart meters, eliminating collection risk because stall and shop owners will prepay for electricity.

The end-user tariff is subject to adjustments that the three parties agree to and are approved by NERC.[24] The original tripartite agreement allows for automatic tariff adjustment for minor changes in their costs (NERC needs to be informed in writing, but its approval is not required). However, to address impacts on the project from increases in AEDC's bulk power tariff and from macroeconomic conditions beyond its control—and to avoid the need for frequent negotiations in the future—GVE has proposed an amendment to the tripartite agreement that will codify the formula according to which the end-user tariffs will be revised and automatically adjusted. If approved, the amendment will automatically trigger an end-user tariff adjustment upon a 5 percent increase in GVE's cost of service.

Benefits of the tripartite agreement to shop and stall owners

To evaluate the potential benefits of the mini grid project for Wuse shop and stall owners, Nigeria's Rural Electrification Agency paid for an energy audit of the market to determine pre–mini grid consumption levels and supply sources. The audit determined that a typical owner received electricity from two sources: (1) small petroleum or diesel generators owned and operated by individual shopkeepers, and (2) the grid electricity supplied by AEDC. Because AEDC was not able to provide a continuous supply, it was estimated that about half of owners' electricity supply came from their on-site diesel and petroleum generators. Each owner spent, on average, N9,561 (US$23.15) on electricity produced from its generator and N3,031 (US$7.34) on the grid electricity produced by AEDC, for a total monthly expenditure of approximately N12,600 (US$30.51). The average blended cost of these two supply sources was US$0.38/kWh.

In the pre–mini grid period, owners paid AEDC N32 (US$0.077)/kWh under a retail tariff approved by NERC. For the self-generated electricity, it is estimated that owners paid an effective price of N120–N300 (US$0.291–US$0.726)/kWh. Once the mini grid becomes operational, the tripartite agreement specifies that owners will pay N55 (US$0.133)/kWh to GVE, which is considerably less than the blended price of US$0.38 they paid before the mini grid became operational.

Under the tripartite agreement, the average unit price of grid electricity rose from N32 (US$0.077) to N55 (US$0.133) for each owner, but the average monthly electricity cost fell about 40 percent and the supply became more reliable. However, GVE's cost of service has increased considerably since the tripartite agreement was signed on October 18, 2019. GVE expects that it will need to renegotiate the end-user tariff in order to recover its increased costs. In addition to AEDC's bulk sales tariff rising from N36.00 (US$0.087)/kWh to N54.13 (US$0.131)/kWh, Nigeria's inflation rate almost doubled, from 9 percent to 17 percent, since the agreement was negotiated. Initially, the exchange rate was about N360/US$1, and the official and parallel exchange market rates were relatively close to one another. By the time GVE procured most of the equipment for the project, the parallel exchange market rate had increased to about N550/US$1.[25] The previously negotiated end-user tariff of N55.00/kWh is now almost equal to the prevailing AEDC bulk sales tariff of N54.13/kWh.

The changes noted made it unfeasible for GVE to serve the Wuse market at the originally negotiated tariff. The revised tariff will need to be below the owners' blended cost of procuring electricity today. That cost, calculated at US$0.38/kWh, has also gone up considerably since May 2023 as a result of large increases in the price of the petrol and diesel needed to run the small on-site backup generators.[26] Once the interconnection is complete and the mini grid starts supplying electricity, GVE expects to renegotiate the end-user tariff with WUMATA to recover its increased costs.

Benefits of the tripartite agreement to the Disco

When AEDC was the Wuse market's retail electricity supplier, it was allowed to charge owners N32 (US$0.077)/kWh. The arrival of the mini grid will allow AEDC to transform itself from a retail supplier to a wholesale one. AEDC estimates that its volume of electricity sales to the market will increase and that its collection rate will go up from 67 percent as a retail supplier to close to 100 percent as a wholesale supplier. AEDC will also earn additional revenue of N12 (US$0.029)/kWh from the DUOS fee GVE will pay for the use of AEDC's existing distribution system. When the mini grid goes into operation for the entire market, AEDC estimates that its related revenues will rise by about 70 percent. About 95 percent of its revenues will come from power sales and about 5 percent from the DUOS charges for use of the AEDC distribution system.

Technical design and operations

The project is designed to dispatch power from four sources: grid supply from AEDC, self-supply from the 1 MW PV solar plant, up to 1.2 MWh of battery storage, and occasionally electricity generated by the 1 MW diesel generator. The instantaneous power dispatch will be automatically controlled in real time by an intelligent microgrid controller embedded in a compact 1 MW/1.2 MWh energy storage system from Jinko Energy Solution, the first of its kind in Sub-Saharan Africa. The project will also use ultra-high-efficiency PV modules employing Jinko Solar's new tiling ribbon technology (refer to photo 2.6). This technology optimizes roof space and balance of system requirements, an especially important feature in an urban market, where roof space is very limited.

The Wuse mini grid will be attached to a 33 kV network that also connects other non–mini grid customers of AEDC. If there is a shortage of upstream electricity supply, AEDC has to ensure that the Wuse mini grid will receive the limited supply before other non–mini grid communities that are attached to the same 33 KV network. It is anticipated that the limited supply will be routed to the Wuse market mini grid using auto-recloser switches, which AEDC can control remotely.

The project also includes enhanced distribution automation, switching, and control infrastructure to ensure effective demand-side management, fault detection and prevention, and active load management in real time. Customers will be metered using GVE's smart prepayment meters, which are fitted with antitheft and antitampering features controlled by a sophisticated platform for advanced metering infrastructure and automated meter reading. The billing system supports a wide variety of both physical and contactless vending options.

Public relations and education campaign

GVE commissioned a public relations, communications, and energy efficiency advocacy campaign in the market designed to remind shop and stall owners of the pre–mini grid service and cost realities. The campaign will compare the

PHOTO 2.6

Aerial photo of the solar panels powering the mini grid on top of buildings in the Wuse market, Abuja, Nigeria

Source: ©Ifeanyi Orajaki. Used with permission; further permission required for reuse.

impacts of the ongoing pilot project with the expectations of shop and stall owners. The campaign, which has been ongoing for about a year, is also aimed at educating shop and stall owners about energy efficiency best practices.

CASE 4: TATA POWER'S RENEWABLE MICROGRIDS INITIATIVE (INDIA)

In November 2019, Tata Power—India's largest private power company, with annual revenues of US$5.5 billion—announced an initiative to build 10,000 green microgrids in rural villages. The initiative will be undertaken by Tata Power Renewable Microgrid (TPRMG), a subsidiary of Tata Power. TPRMG estimates that these microgrids will reach about 5 million households and approximately 25 million people in the next 5 to 6 years. TPRMG also plans to electrify 100,000 rural enterprises and provide irrigation to 400,000 farmers.

In its first year of operation, TPRMG set up microgrids in villages in the states of Bihar and Uttar Pradesh, the first of which was commissioned on February 7, 2020. The program rollout was slowed by the outbreak of the COVID-19 pandemic in early 2020, but TPRMG was nevertheless able to commission its 100th microgrid on January 26, 2021, less than a year after the installation of the first. By March 31, 2023, it had 200 microgrids up and running, with a total installed capacity of more than 6 MW, and was serving more than 20,500 unique customers.[27] The dramatic effects of the microgrid's arrival are illustrated in photo 2.7. In coming years, TPRMG plans to install microgrids in other states, such as Assam, Jharkhand, Madhya Pradesh, and Odisha.

All TPRMG microgrids will initially be non-interconnected. In each village, TPRMG will install both a new microgrid generating system and a separate new distribution system. The absence of an electrical connection to the local Disco means that the TPRMG microgrid will not initially be able to make power transactions with the Disco. The microgrids could conceivably interconnect to the local Disco in the future, if interconnection were to become commercially advantageous for both parties. For this to happen, however, changes will likely have to be made in the Indian regulatory system, at both the central and the state levels, to provide economic incentives for the Disco and TPRMG to switch over from a non-interconnected to an interconnected microgrid.

In the meantime, TPRMG is complementing the efforts made by local Discos to provide electricity to rural consumers. It encourages its customers to purchase lower-priced Disco electricity whenever it is available. However, Discos are not always a reliable source of electricity (especially during summer daytime hours when the load requirement is very high across all the states of India). TPRMG's microgrids are able to provide reliable electricity supplies at all hours. Their greater reliability is especially important for businesses engaged in time-sensitive agricultural production and processing.

Technical design

TPRMG uses a standard microgrid equipment package that is essentially the same at all locations, allowing TPRMG to achieve economies of scale that would not be possible if each site required its own design. The standard package consists of a 30 kWp solar array, a lead-acid battery with 30 kWh of usable energy storage, a 25 kVA diesel generation set, and two 15 kVA inverters. Lead-acid

TPRMG uses a standard microgrid equipment package that is essentially the same at all locations, allowing TPRMG to achieve economies of scale that would not be possible if each site required its own design.

PHOTO 2.7

The same street moments before and after power from the TPRMG microgrid was switched on, Sunheri Chauraha village, Uttar Pradesh state, India

a. Before power was switched on

b. After power was switched on

Source: ©Tata Power Renewable Microgrid (TPRMG). Used with permission; further permission required for reuse.

batteries are used in place of lithium-ion because TPRMG has concluded that they have proven to be more reliable, cost-effective, and suitable for the rural Indian environment.

TPRMG is also exploring new battery technologies for its standard package. In December 2022, the company installed vanadium redox flow batteries on a pilot basis at two village sites in Uttar Pradesh. These batteries have several potential advantages compared with lead-acid batteries. They can be discharged to almost 100 percent and then recharged fully. They can also operate within a wider temperature range (-5°C to + 50°C) and with an energy efficiency of 75–80 percent. The flow batteries also have a longer operating life (20 years or more, compared with the current 3–5 years for a lead-acid battery). If these technical advantages are achieved in the two field tests, TPRMG expects that the lifetime levelized costs of the flow batteries could be 25 percent lower than those of the lead-acid batteries currently used.

TPRMG is also testing zinc gel batteries, which are similar in chemistry to the vanadium redox flow batteries but have better thermal stability characteristics, especially at subzero Celsius temperatures; have better energy efficiency (80–90 percent); and need no auxiliary electricity to operate and maintain. TPRMG plans to start field trials of the zinc gel batteries in December 2023.

TPRMG's standard microgrid serves about 100–150 customers. The microgrids are built to power machines with maximum loads as high as 7.5–11.2 kW. To enhance safety against electric shock, all distribution lines are insulated; the use of aerial bunched cables also prevents "hooking"—creating an illegal connection by tapping into a low-voltage line.

The basic generation system is typically installed on a parcel of land of about 1,250 square meters, which is usually leased from a local farmer under a 25-year lease. TPRMG tries to create clusters of microgrids to save on operation and maintenance. The ideal cluster would typically consist of 30–40 microgrids no more than 15–30 kilometers apart. Over time, TPRMG plans to increase cluster density by building new microgrids within the cluster area. The basic equipment package is modular; therefore, it should be relatively easy for TPRMG to scale up the installed equipment at a site if the number of customers or the amount of their consumption increases.

TPRMG tries to create clusters of microgrids to save on operation and maintenance. The ideal cluster would typically consist of 30–40 microgrids no more than 15–30 kilometers apart.

TPRMG has created several technological innovations in its standard equipment package. Its "microgrid in a box," or MIB (refer to photo 2.8) is a

PHOTO 2.8
TPRMG's "microgrid in a box"

Source: ©Tata Power Renewable Microgrid (TPRMG). Used with permission; further permission required for reuse.
Note: The "microgrid in a box" is the structure on the right. The diesel generator stands alone on a platform to the left. The equipment is elevated in order to protect against flooding, increase natural cooling, and reduce the risk of damage from dust, insects, and animals.

preassembled, thermally insulated, temperature-controlled, modular mini grid system that delivers a full turnkey system with comprehensive hardware (including inverters that convert direct current to alternating current [AC] power, an energy storage system [batteries], and an in-house energy monitoring and control system); end-to-end installation; and an after-sales service package provided by Tata Power Solar Systems Limited, another fully owned Tata subsidiary.

The MIB protects sensitive equipment from the strong heat of Indian summers and torrential monsoons as well as against the theft of batteries. It reduces installation and commissioning time from months to days. TPRMG estimates that the MIB has reduced its capital costs by 10–15 percent for each microgrid.

Within the MIB is a minicomputer that communicates via radio waves with customers' smart meters. It also communicates with TPRMG's central web server. Thus, all smart meters for TPRMG's 20,000+ customers can be monitored and controlled remotely.

TPRMG has also implemented a home-grown energy management solution (i-TAPS). This system is installed in each microgrid, including the MIB, and collects data on system status, such as various electrical parameters (for example, plant loading, voltage, frequency, and current) at each microgrid node. The i-TAPS system communicates with TPRMG's central cloud server via India's telecommunication system (global system for mobile communications and general packet radio service), which can alert the microgrid operator and technicians about local abnormal electrical conditions. TPRMG's central control cloud server can monitor the performance of all of TPRMG's microgrids.

TPRMG reports that it is constantly looking for ways to improve the operating efficiency, running costs, and physical security of its standard equipment package. In addition to testing new battery technologies, as discussed earlier, the company is also testing smaller inverters that are better able to handle sudden changes in machinery-driven loads, rooftop turbine ventilators (for heat dissipation without using electricity), locally sourced eco-friendly materials for constructing microgrid control rooms, and solar cameras to improve security. TPRMG aims to reduce the capital cost by 15–20 percent of the original overall system design.

Replacing diesel generators with biomethane generators

Within the standard equipment package, TPRMG is also exploring the feasibility of replacing the backup 25 kVA diesel generator with a 25–30 kVA biomethane generator (refer to photo 2.9). In most instances, the methane will be produced in anaerobic biogas digesters from locally available cow dung or agricultural waste or press mud (a waste product of sugar mills). The methane will be used to power gas generators for several hours to (1) produce backup electricity when the sun is not shining, (2) meet peak demands that cannot be completely served by other supply sources, and (3) provide electricity for nighttime loads (for example, for agricultural processing plants) or for early morning loads to avoid the need to draw down higher-cost electricity from backup batteries. The biogas digesters will produce organic fertilizer as a by-product that can be used by local farmers.

In some locations, it may be more efficient to locate a larger, centralized biogas digester plant near a large gaushala (a cow shelter for 150–500 cows). Once the gas is produced at this central location, it will be compressed, transported in

PHOTO 2.9
Biogas plant at the Basaitha microgrid in Bihar, India

Source: ©Tata Power Renewable Microgrid. Used with permission; further permission required for reuse.
Note: The large, inflated tan structure is the biogas digester, which creates methane from cow dung. The white inflated structure is a balloon for additional biogas storage.

tanks, and expanded into storage cylinders at TPRMG's nearby microgrids, where it will be used to generate electricity through a gas generator.

Building on the Bihar pilot, TPRMG is now launching a new pilot in Uttar Pradesh to test the feasibility of replacing diesel generation with biomethane produced from different sources of agricultural waste (wheat, rice, corn husk, rice husk, Napier grass, and press mud). The plan for the new pilot is to use a hub-and-spoke model developed for the Bihar pilot. The biomethane will be produced at a central location (the hub) and then trucked out to 10–12 different nearby villages with TPRMG microgrids, where it will be used to generate electricity. If the new Uttar Pradesh pilot is successful, it has the potential to reduce TPRMG's operating costs by replacing electricity produced by diesel generators with electricity produced from gasified agricultural waste.

Distribution and metering

The standard modular microgrid system typically serves about 150–200 households. The distribution system uses aerial bundled conductors hung from cement poles. TPRMG's microgrids are able to connect with the local Discos' distribution systems, if required in future. The total length of the distribution network is 2.0–2.5 kilometers and includes only low-voltage (220–440 V) wires. Individual customers can choose to connect either at 440 V (three-phase AC) or at 220 V (single-phase AC). Customers that require 440 volts are typically microenterprises (for example, oil expellers, flour mills, rice hullers, and masala pulverizers); industrial consumers (for example, utensil and furniture manufacturers, packaging plants, bakeries, and ice cream producers); and commercial and nonprofit installations (for example, showrooms, educational institutes, hospitals, and pathology and diagnostic centers). Households and small shops typically need only 220 V (single-phase AC).

All TPRMG customers are individually metered, but the metering systems differ by customer class. Low-consumption residential customers are on clustered prepaid Group SMART meters. Higher-consuming customers use postpaid meters.

Low-consumption customers use patented Group SMART meters developed by the Institute for Transformative Technologies working closely with Tata Power. A single Group SMART meter monitors and controls the consumption of up to six low-consumption customers (four electrical connections with loads of up to 500 watts [W] each and two electrical connections with loads of up to 2,000 W each). The meter is typically mounted about 5 meters (15 feet) up on a concrete distribution pole (refer to photo 2.10). Operating in combination with two-way communication, it has the following capabilities:

- **Monitoring.** The meter monitors electricity consumption and other electrical parameters[28] of individual customers.
- **Controlling.** Customers can choose to receive electricity with maximum loads that can vary from 25 W to 2,000 W. If the load exceeds the contracted load of the customer, then the meter will automatically cut off supply on the overload and wait a few minutes to reconnect automatically. If the overload persists, then the load is automatically disconnected once again. This process is repeated twice, and then the load is disconnected from supply. Supply can be restored with human intervention by an authorized representative of TPRMG, subject to reduction of the load to within the contracted limit.
- **Time-of-day supply.** Customers can opt for service in different time slots (for example, from 8 am to 10 am or from 5 pm to 10 pm) or other time slots that meet the customer's supply needs.
- **Payment packages.** Prepayment packages with different tariffs for different customer groups (for example, residential, commercial, and irrigation) are available to customers. The load is shut off if the customer's prepaid credits run out.

Service is provided to low-consumption customers through a switchboard installed on customers' premises as part of their connection package. The switchboard, which provides three switches for lights and a single electrical outlet (refer to photo 2.11), is protected by a miniature circuit breaker that provides overcurrent protection as well as the ability to shut off electricity manually.

Higher-consumption customers, such as microenterprises, farmers, and industrial or larger commercial customers, use postpaid electronic meters that record electrical parameters such as voltage, current, power factor, active and reactive power, and electricity consumption at the customer node. Unlike the Group SMART meters used for prepaid customers, these electronic meters do not have remote control features. TPRMG is in the process of procuring low-cost versions of smart meters that will have remote control capability for these postpaid customers.

PHOTO 2.10

Group SMART meter used by TPRMG

Source: ©Tata Power Renewable Microgrid (TPRMG). Used with permission; further permission required for reuse.

Note: The Group SMART meter, which can serve six prepaid customers, is the lower box. The upper box is an isolator that isolates the meter from the grid power supply when work is being done on the meter.

PHOTO 2.11

TPRMG's household switchboard, including a miniature circuit breaker, three switches for light fixtures, and an outlet

Source: ©Tata Power Renewable Microgrid (TPRMG). Used with permission; further permission required for reuse.

Connection and service packages

As noted earlier, TPRMG offers connection and service packages tailored to various customers' needs. The selected package determines the maximum wattage the customer can use, which determines how many light bulbs and appliances can be turned on at the same time. Once customers select their connection package, they must specify how many hours of service they wish to receive each day and when in the day they require the service.

The basic household connection package (Household Basic-1) includes a switchboard, one 10 W light-emitting diode (LED) bulb, and wiring from the Group SMART meter to the switchboard in the customer's house. The basic package has a 30 W load capability, so a customer could add an additional 10 W LED light bulb and a mobile phone charger. (TPRMG does not supply these items.) The one-time connection charge for the Household Basic-1 package is Rs 350, plus taxes, for a total of Rs 413 (US$4.80). The monthly electricity bill is Rs 150 (US$2.07).[29] Households that choose the Household Basic-1 package are allowed to take 4 hours of service per day. The households have the option of taking the electricity service in a single time slot (for example, 5 pm to 9 pm) or in two time slots (for example, 10 am to 11 am and 5 pm to 8 pm).

TPRMG offers a total of four household connection packages. The packages range in wattage from 30 W to 1,000 W, with service from 4–6 hours per day. The top package allows a household to connect lights and appliances (for example, televisions, coolers, and heaters) with a maximum load capacity of 1,000 W. TPRMG offers customers the flexibility of switching between packages without penalties at any time during a monthly billing period. To date, about 80 percent of household customers start with the Household Basic-1 package, 15 percent choose a middle package, and 5 percent choose the highest package.

In the summer, about 20 percent of customers move up to a service package that allows them to connect more fans, coolers, and air conditioners. Once the summer season ends, most of those customers return to a lower-service package.

However, TPRMG is currently gathering evidence on the percentage of customers that migrate to higher packages and then remain in the higher package. It is expected that this stable (rather than seasonal) upward migration will increase over time as households acquire more energy-efficient home appliances under different financing programs (discussed in a later subsection).

In addition to the household service packages, TPRMG offers service packages for three other major customer classes:

1. **Shops.** Shopkeepers (for example, mom-and-pop shops) typically use microgrid supply for basic lighting and cooling purposes under four different packages, with loads starting at 40 W and going up to 1,000 W.
2. **Microenterprises.** Microenterprise customers have the option of purchasing electricity in 4- or 8-hour packages. They usually have loads starting at 5 kW and going as high as 15 kW, and may pay based on their consumption in the prior billing period.
3. **C&I consumers.** Commercial consumers generally consume electricity mostly for lighting, heating, cooling, and processing purposes. Their load generally ranges from 1 kW to 5 kW. Industrial consumers generally use electricity to power machinery for production purposes, with loads ranging from 5 kW to 25 kW.

TPRMG is able to simultaneously offer different service packages to different customers on a single mini grid. It can do so thanks to the smart meters that are available to all customers and the accompanying software that was developed to make full use of the meters' measuring and control capabilities. Customers can self-select their tier service and migrate at their own pace to higher levels of electricity service. The various service packages bear some resemblance to the Multi-Tier Framework proposed by the Energy Sector Management Assistance Program (ESMAP) in 2015 (refer to ESMAP 2015, Table ES.1). One important difference is that all customers in TPRMG's low-, medium-, and high-service packages receive the same high level of reliability. In contrast, the Multi-Tier Framework, as originally conceived, assumes that reliability improves as a customer moves from a lower to a higher tier of service.

Tariff structure and level

All customer service packages include a fixed charge and a variable charge based on the volume of electricity consumed. TPRMG has the ability to charge tariffs according to when the electricity is consumed (peak or off peak) and expects to activate these time-of-use tariffs for C&I customers by December 2023. Tariffs will be lower during daylight hours (10 am–4 pm, when the sun is strongest).

Like the tariffs of most microgrids, TPRMG's tariffs will be higher than the Disco's tariff, because state-owned Discos are compelled (for social and political reasons) to set household tariffs significantly below cost-recovery levels. Despite its higher tariffs, TPRMG has signed up household customers because it can supply electricity that is more reliable (fewer unplanned outages) and of higher quality (less variation in frequency and voltage) than what customers receive from the local Disco. TPRMG can attract and retain customers because it provides better service, both technically and commercially, than the service available from most state-owned Discos.

Despite its higher tariffs, TPRMG has signed up household customers because it can supply electricity that is more reliable (fewer unplanned outages) and of higher quality (less variation in frequency and voltage) than what customers receive from the local Disco.

Financing for customers

TPRMG has arranged for a microfinance institution to provide loans for energy-efficient appliances and machinery to all segments of customers. These purchases can be paid for in installments, typically in six monthly payments, with the bills coming directly from the microfinance institution. Among households, the mostly commonly financed appliances are LED lights, fans, refrigerators, and televisions. Among businesses, loans have been used to replace diesel-powered flour mill motors and irrigation pumps with electricity-powered versions (refer to photo 2.12). The switch from diesel- to electricity-powered machines reduces noise and air pollution and reportedly saves operators about 25–35 percent in operating costs, depending on diesel prices.

Billing

Initially, TPRMG collected cash payments from microgrid customers by going door to door. It then established a system that allowed customers to make payments by going to a local agent authorized by a payment bank in the village.

Recently, TPRMG adopted a new payment system, the Bharat Bill Payment System (BBPS) developed by the National Payments Corporation of India. Customers can either make cash payments to an authorized BBPS-enabled local village entrepreneur (often in a small grocery store) or make digital payments directly via a BBPS-enabled mobile phone app. The BBPS also allows a third party to make payments for a TPRMG customer. For example, a son working in Delhi could make payments to the TPRMG account of his parents in a village several hundred kilometers away.

The BBPS has advantages for both TPRMG and its customers. For TPRMG, it reduces the cost of collections and the time before the customer's payment arrives. For customers, it offers convenience. The share of digital payments, by value, rose from 13 percent of total payments in October 2020 to 98 percent in August 2023. The BBPS mobile app accounts for approximately 90 percent of total digital payments; payment banks, customer service centers, and others account for 8 percent. The remaining 2 percent of payments are collected in cash by TPRMG's authorized representatives.

Use of microgrids as a backup or a sole source of electricity

Many households and shops maintain physical connections to both the local Disco and TPRMG. The TPRMG supply is a backup for these customers . . . .

Many households and shops maintain physical connections to both the local Disco and TPRMG. The TPRMG supply is a backup for these customers, who typically take electricity from TPRMG only when the local Disco is unable to supply electricity, which often occurs during early evening hours, when households and shops need lighting and cooling. If the Disco is unable to supply electricity, a household customer manually removes the cord from the outlet connected to the Disco system and inserts it into the outlet connected to the TPRMG system. Some shops use a manual changeover switch. A few critical-load consumers use automatic changeover switches.

In contrast, about 100 C&I customers—including microenterprises such as flour mills and oil expellers that grind seeds for oil—connect only to the TPRMG system. Most of these customers were never connected to the local Disco because they found the service to be too unreliable. Before the arrival of the TPRMG microgrid, they used their own on-site diesel generators to power their machines.

PHOTO 2.12

Diesel-powered (top) versus electricity-powered (bottom) flour milling machine

a. Diesel-powered machine

b. Electric-powered machine

Source: ©Tata Power Renewable Microgrid. Used with permission; further permission required for reuse.

With the arrival of a TPRMG microgrid, they opted to connect only to the TPRMG system and switched to electrically powered motors. TPRMG estimates that its supply saves these customers about 20–30 percent in electricity costs compared with self-supply from diesel generators. With recent increases in the price of diesel, the savings have increased to about 25–35 percent.

Automated customer service

Toll-free number. Currently, customers with queries or complaints call the TPRMG representative responsible for their village or cluster of villages. However, TPRMG plans to move to a centralized form of customer service. Tata Power, TPRMG's parent company, already offers 24-hour customer service through a toll-free number for customers in Ajmer, Delhi, Mumbai, and Odisha. TPRMG is deliberating whether it should also connect its microgrid customers to a toll-free number. If this new system is implemented, a customer will be connected to an automated system that handles common requests and complaints. The customer's mobile number will be tied to the customer's TPRMG account, making the automated system able to answer many frequently asked questions. If the automated system does not understand a question, the customer has the option to be connected to a live agent. TPRMG plans to develop a system that will be able to respond in English, Hindi, and local languages. Customers will be able to reach the central customer service number around the clock.

Customer mobile app/chat service. While TPRMG is evaluating whether to offer a staffed toll-free customer service number to its microgrid customers, it will offer an interactive WhatsApp chat service and a messaging option on a TPRMG-designed consumer mobile app. The chat service will be tied to a customer's account, allowing the customer to obtain routine information on billing and electricity usage and to make queries and complaints. The customer will be able to use the service in English, Hindi, and several other languages through the texting feature on the customer's mobile phone. The chat service will not be staffed by a live agent. Instead, the responses will be automatically tied to the customer's account.

Partnership

Tata Power finances TPRMG; currently, no other parties are involved. Once the initial pilot technologies and business innovations are tested and accepted, TPRMG will explore third-party financing to achieve a more rapid scale-up. TPRMG reports that it has not received any subsidies (grants or other kinds of subsidies) from national or state governments.

In November 2019, Tata Power announced a partnership with the Rockefeller Foundation. It worked with two Rockefeller Foundation subsidiaries: (1) Smart Power India (now called Global Energy Alliance for People and Planet), which provided project- and demand-management services, and (2) the Institute for Transformative Technologies, which provided meter-management services to TPRMG.

Demand promotion and management help microgrids achieve commercial viability. TPRMG encourages the creation of village-level enterprises that can start new businesses using TPRMG's reliable and affordable power supply. Perhaps the biggest potential increase in demand can come from larger non-grid-connected businesses—usually commercial customers that were never connected to the Disco because they found its supply too unreliable. TPRMG and several other partners worked closely with these businesses to show them how to convert diesel-operated machines to motors powered by electricity supplied by TPRMG. These businesses were connected to microcredit institutions that provide loans to purchase the new electricity-powered equipment. The loans are typically paid off in installments over a 3- to 6-month period.

Other TPRMG programs to promote affordable and clean electricity for customers

In addition to providing a round-the-clock electricity supply, TPRMG is testing several programs to reduce energy and economic poverty, cut carbon emissions in communities, and promote productive uses of electricity. The goal is to produce a win-win commercial and environmental outcome for TPRMG and its customers. Because these initiatives are in various stages of development, it remains to be seen which will be successful and how they can best complement the operation of TPRMG's microgrids. The key programs are described in the following paragraphs.

Khushiyon Ka Kanekshan ("connection of happiness"). This initiative seeks to reach the poorest people in every community served. For various reasons, these households and shops did not receive electricity from the local Disco. Once TPRMG connects them to its microgrid, they will pay the same Rs 150 (US$2.07) monthly charge as more prosperous customers for the lowest-consumption package. As of August 2023, some 600 households and shops had become TPRMG microgrid customers under this initiative. TPRMG is in discussions with several philanthropic organizations that may be able to provide partial or full grants to cover the one-time service connection charge for the very poorest households.

Water as a service. This initiative was launched by TPRMG on December 23, 2021 (Kisan Diwas, or Farmers Day), to encourage farmers to switch from diesel-powered irrigation pumps to electric pumps to reduce their irrigation costs. Some farmers who purchase the pump also buy movable flexible piping, allowing them to resell pumped water to neighboring farmers and earn additional income. TPRMG estimates that neighboring farmers can save up to 30–35 percent of the current cost of irrigating their land with their own diesel-powered pumps. The savings for the neighboring farmer will depend on the price charged for the water pumped from the new electric pump installed on the property of the TPRMG microgrid customer. When a farmer already has a pump powered by electricity purchased from the local Disco (estimated at 5–20 percent of farmers in a typical village), the Disco-supplied electricity is usually available only at night. In contrast, a TPRMG microgrid can supply electricity during the day, eliminating the need for the farmer to get out of bed in the middle of the night to move the irrigation pipes to different parts of the field.

Diesel generation to microgrid generation. This initiative was launched by TPRMG on June 5, 2021 (World Environment Day), to encourage customers to migrate from diesel-powered machines to electricity-powered machines. TPRMG will buy electric motors and electric pumps in bulk for resale to microenterprises and individual farmers, who will have the option to pay for the equipment in installments over a 6-month period. TPRMG estimates that farmers can recoup the capital investment of the electric-powered pumps through 5 to 7 months of operating-cost savings.

Greeni. On October 2, 2022 (Gandhi Jayanti Day), TPRMG and the Small Industries Development Bank of India, a central government entity, announced a joint program, called Greeni, to establish or expand 1,000 small businesses to be served by TPRMG green electricity at existing or future TPRMG microgrid sites. TPRMG will help select eligible businesses. The Small Industries Development Bank will provide grants and concessional loans with better financing terms (for example, lower down payments and longer loan durations) to the selected enterprises to reduce the capital costs of new electricity-powered machines.

Efficiency as a service. Many of TPRMG's rural customers (including microenterprises) continue to use appliances, machines, and tools that are not energy-efficient. These customers typically are not aware of more efficient products that can lower their energy usage and increase their income. On March 3, 2023 (the Tata Group Founder's Day), TPRMG rolled out a "Less Is More" initiative under Tata Power's general theme of "Sustainable Is Attainable." The objective is to enable TPRMG's customers to acquire (1) energy-efficient appliances (such as brushless direct current fans, coolers, heaters, and TVs), and (2) energy-efficient machines (motors, pumps, deep freezers, and refrigerators).

Energy as a service. The objective of this initiative, launched on September 15, 2023 (Engineers Day), is to meet the needs of rural customers for thermal and electric energy. For cooking needs, TPRMG is piloting the provision of green biomethane gas for cooking combined with energy-efficient cookstoves. The green biomethane gas will be produced by TPRMG at new central biomethane production locations. (Refer to the earlier discussion of TPRMG's pilot biomethane plants.) If the pilot is successful, the gas will be used in two ways: to replace diesel generation at microgrid sites and to be sold at retail for cooking at hotels and large and small village and roadside restaurants.

The biomethane gas will reduce the environmental impact of cooking because it can be combined with cookstoves having thermal efficiencies of 60–70 percent, much higher than the cookstoves currently in use in both large and small restaurants. The stoves will also use an innovative burner design that is projected to achieve a 30–40 percent fuel savings. TPRMG is collaborating with several companies to make these technologies and products available to rural hotels, villages, and roadside restaurants. The restaurants will benefit from lower operating costs and little or no soot production. TPRMG will benefit from the sale of the green methane gas—an additional revenue stream.

Electric vehicle charging as a service. In India, the use of electric vehicles (buses, cars, bikes, and scooters) has spiked because of the growing availability of commercial charging stations. In rural India, however, the penetration of e-rickshaws and e-carts (three-wheeled electric vehicles for transporting people and materials, respectively) has lagged because of slow growth in the availability of commercial charging stations. At present, rural e-rickshaw and e-cart operators typically charge their electric vehicles at home during the night (6–8 hours for lead-acid batteries and 2–4 hours for lithium-ion batteries). During the day, they can travel 100–125 kilometers on a single charge, but they cannot go beyond this distance because charging stations are scarce in rural markets. TPRMG is collaborating with a private company to provide a green electricity supply to the charging stations and battery-swapping locations for e-rickshaw and e-cart operators in rural markets, which will enable drivers to cover more distance each day. TPRMG will benefit from additional revenues from sales of energy to charging or battery-swapping stations.

CASE 5: HUSK POWER SYSTEMS' PROJECTS (INDIA, NIGERIA, AND TANZANIA)

Founded in 2008, Husk Power Systems (www.huskpowersystems.com) owns and operates 200 community solar mini grids in India, Nigeria, and Tanzania.[30] Its portfolio of more than 150 mini grids in India, located in the states of Bihar and Uttar Pradesh, has a total installed capacity of about 8.5 MW and provides 24/7 electricity to households and roughly 10,000 small businesses. In November 2021, Husk began operating its first 6 mini grids in Nigeria's Nasarawa state, increasing the number to 12 within months. At present, it is the only company building and operating rural mini grids in both Africa and Asia.

To date, Husk's mini grids are not connected to Discos. In Nigeria and Tanzania, the mini grids are in geographically isolated locations. In India, most of Husk's mini grids are located in villages and towns that already receive limited electrical service from a state-owned Disco. In July 2023, Husk reported that it expects to build and operate several interconnected mini grids under an agreement with one of Nigeria's 11 Discos.

Established in the Global South by entrepreneurs from that region, Husk employs more than 400 people and focuses on developing local managerial and technical talent. One hundred percent of its employees in India, Nigeria, and Tanzania are citizens of the countries in which they work.

Husk is also working to ensure gender balance throughout its operations and to provide targeted products and services to empower women customers. It has a near-term goal of being compliant with guidelines of the 2X Challenge (https://www.2xchallenge.org), a Group of Seven Summit initiative that is mobilizing development finance institutions' investment in companies providing greater economic opportunity to women in developing markets.

In India, Husk uses a hybrid supply system consisting of solar PV, batteries, and a biomass gasification system. The initial system size is typically about 50 kW of installed capacity. Solar PV panels in India average 30 kWp of capacity, with the remaining capacity coming from biomass. Husk adds generating capacity as demand increases. In some instances, the additional capacity comes from a biomass gasification system powered by rice husks and other types of agricultural waste.

Husk uses a standardized, modular approach at its sites in India. Most of the equipment is fabricated off site and then trucked to a village for installation, reducing both the project cost and the time to get a new site up and running. As an additional cost-saving measure, Husk builds its mini grids in clusters and uses its own staff to operate all of its mini grid assets.

Husk uses a standardized, modular approach at its sites in India. Most of the equipment is fabricated off site and then trucked to a village for installation, reducing both the project cost and the time to get a new site up and running.

Like most privately owned mini grid developers in India, Husk has not attempted to lease the local Disco's distribution system. Most state-owned Discos in India have been reluctant to share their existing distribution facilities with mini grids. In Nigeria, however, Husk expects it will be able to lease portions of a local, privately owned Disco's distribution system in towns and villages where it intends to build and operate new undergrid mini grids. If that effort is successful, it should reduce Husk's up-front investment in distribution. However, among the communities hosting the first 12 mini grids Husk set up in Nigeria, there was no existing distribution infrastructure to lease.

At every location, solar PV serves as the main source of power. A PV system is combined with a biomass power plant system to meet electricity demand on rainy and foggy days. Excess electricity produced is used to charge the battery.

About 75 percent of the electricity generated at a typical Husk mini grid in India and Nigeria is produced by solar PV panels.

Husk's proprietary biomass gasification system is switched on at about 5 pm and can operate until 11 pm. Husk estimates that the levelized cost of electricity (LCOE) from its gasification system at full load is 30 percent cheaper than the LCOE from diesel generation and 35 percent cheaper than the LCOE from battery storage.[31] This in turn lowers the cost of electricity produced at night. Husk has largely automated the gasification system so that it does not require a full-time, on-site operator.[32]

Husk's biomass system

The Husk-designed biomass gasification system uses a standard producer gas engine, which ensures stable operation with varying quality of biomass waste feedstock (rice husk or corn cobs). A proprietary cooling system prevents water from coming into contact with the synthetic gas, allowing the water to remain uncontaminated and reusable in hundreds of cycles.

Several by-products have commercial value. Rice husk char, for example, can be used in incense sticks or fertilizer and, with chemical treatment, can be used to produce precipitated silica (in turn used to manufacture tires).

Battery backup

Husk's standard configuration includes a valve-regulated lead-acid battery.[33] The battery acts as the mini grid's main power source between 11 pm and 7 am and can also act as a backup supply source between 7 am and 11 pm if the solar PV and biomass are not functioning as expected. The batteries are designed for up to 6 hours of autonomous operation. The cost of electricity stored in the batteries includes both the electricity (taking into account what is lost to inefficiency in the charge-discharge cycle) and the wear and tear on the battery itself (refer to appendix G).

Cost performance

Husk reduced its CAPEX in India (including for poles, wires, civil works, smart prepaid meters, and connections to customers) from US$3/Wp in 2018 to US$2/Wp in 2020.

Husk reduced its CAPEX in India (including for poles, wires, civil works, smart prepaid meters, and connections to customers) from US$3/watt-peak (Wp) in 2018 to US$2/Wp in 2020. It did so through efforts to manage the supply chain (sourcing strategy), optimize system design, and streamline processes from sourcing to installation.

Husk has also increased the lifetime of its assets, extending the life of its lead-acid batteries from 3.5 to 5.0 years, through a battery-management system that ensures that the battery does not discharge too deeply or recharge too much. Husk also reduced the time involved in installing equipment at a new site from about 5–6 weeks in 2018 to about 3 weeks in 2020.

Husk reduced its OPEX by about 40 percent between 2018 and 2020. It reduced its on-site staffing requirements from three full-time-equivalent employees in 2018 to one in 2020.

Because of these reductions, Husk's LCOE at new sites in India was less than US$0.30/kWh in 2021. This cost reflects power generation and operational expenses, customer acquisition costs, and allocation of corporate overheads. The LCOE in Nigeria will likely be higher because the cost of importing components into Nigeria is much higher than into India as a result of higher duties, taxes, and processing costs. In addition, the costs of starting up operations in a new country will inevitably be higher.

Customer categories, hours of service, and consumption patterns and tariffs

In the villages it serves, Husk sells electricity to three types of customers:

1. Households
2. Small businesses (medical supply stores, grocery stores, carpentry shops, garment shops)
3. Factories (rice/maize/spice mills, ice cream/biscuits/rusk manufacturing factories).

Husk bills all customers (except for some financial services businesses) on a prepaid basis, using smart meters. All customers pay for electricity on a kWh basis. Customers receive a 20 percent discount if their monthly consumption equals 120 kWh or higher. Husk also offers a 15–20 percent discount for power consumed during the day, when its production costs are usually lower.

Many of Husk's customers in India are also customers of the local Disco. Residential customers will typically buy Disco power when it is available, at a cost lowered by cross-subsidization and ongoing government financial support. In contrast, many small enterprises that need proper voltage for their machines use mini grid–supplied electricity even when Disco power becomes available. A growing number of Husk's commercial customers disconnected from the local Disco as they became comfortable with Husk's higher reliability. In such cases, Husk became these customers' sole electricity supplier.

Of the energy consumed from a typical Husk mini grid in India, 65 percent is consumed by commercial customers, most of them micro, small, and medium enterprises (MSMEs). Husk estimates that its MSME customers see their energy costs cut by 30 percent, on average, when they connect to Husk mini grids. Before Husk's mini grids became operational, most of these customers typically used a combination of Disco power and diesel generators.

During the COVID-19 pandemic, many Husk customers operating shops were forced to close down for about 4.5 months. To help these small businesses get back on their feet, Husk offered a rolling cash discount of 50 percent for 3 months. Even with these discounts, Husk estimates that 10–15 percent of small businesses were forced to close permanently. Despite these closures, Husk's total revenues increased by about 90 percent in 2020. The increase reflected both the addition of new mini grids and higher average revenue per user of US$12 per month after the end of the lockdown period.[34] Although some village businesses shut down, this reduction in demand was generally offset by increases in household consumption as migrant workers returned from urban centers to their home villages.

Tariffs

Despite charging higher tariffs than the Disco, Husk has signed up and retained new customers. Husk attributes its success to greater service reliability, good power quality (that is, no wide voltage and frequency fluctuations), quick resolution of customers' complaints, and the ability to purchase electrical appliances on credit. Even without a subsidy, Husk believes that it is on a path toward charging a daytime tariff that is less than what Discos charge commercial customers in India.

Husk India does not charge for new connections. The standard connection for a new household customer consists of a prepaid smart meter, a master circuit breaker, and a wire from the nearest pole to the premises of a customer. Although household customers are responsible for changing and upgrading internal wiring, Husk does check the internal wiring of commercial and factory customers. With the consent of customers, Husk-certified electricians change and upgrade the existing wiring to make it more energy-efficient. Customers pay the certified electricians directly for these services.

Husk's average monthly revenue per user has grown consistently, reaching US$12.90 in 2021, up from US$8.00 in 2018.

Husk's average monthly revenue per user has grown consistently, reaching US$12.90 in 2021, up from US$8.00 in 2018. But it has cautioned that its current business model may not be commercially sustainable for other mini grid companies unless they improve costs, service, and demand (box 2.3).

Husk's EBITDA (earnings before interest, taxes, depreciation, and amortization) became positive in the fourth quarter of 2022 in both Nigeria and India.

Husk's EBITDA (earnings before interest, taxes, depreciation, and amortization) became positive in the fourth quarter of 2022 in both India and Nigeria. EBITDA is a measure of operating income because it removes nonoperating and noncash expenditures. Husk's positive EBITDA means its mini grids in Nigeria and India are now earning sufficient revenue to cover their variable and fixed OPEX. To the best of our knowledge, this makes Husk the first and only mini grid company operating solely in developing countries to report operational profitability.[35]

BOX 2.3

Husk Power's road map for the mini grid industry

According to Husk, the current mini grid business model is not sustainable for many developers for the following reasons:

- **Costs are too high.** Most mini grid developers are too small to achieve significant economies of scale. As a result, their costs are too high, making the mini grids' electricity too expensive for many living in poverty.
- **Service is not always better than that provided by the grid.** To be commercially viable, mini grid companies must provide higher-quality service than do existing main grid companies—including greater service reliability, faster resolution of customers' complaints, and better-quality electricity (three-phase alternating current with good voltage and frequency control).
- **Demand is too low.** Companies need to increase demand to boost revenues.

In November 2022, Husk published a road map for the profitable scale-up of the mini grid industry, including the following key performance targets:

- Levelized cost of electricity: US$0.17 per kilowatt-hour
- Uptime: 97 percent
- Average response time to complaints: 1.5 hours
- Average monthly revenue per user: US$12.00
- Capacity utilization: 65 percent.

Actions by the private sector must be complemented by supportive decisions of government regulators and ministries.

Source: Mattson, Sinha, and Brent 2022.

Metering, collections, and remote management

All Husk customers, except some financial services companies, receive electricity services on a prepaid basis. Husk provides them with prepaid smart meters, which include the following features:

- Time-of-day pricing with multiple time intervals
- Energy pricing based on energy use bands (which allows Husk to provide lower rates for high energy users)
- Limitations on customers' maximum instantaneous loads
- Credit control and credit planning.

Husk monitors customers' power generation and consumption in near real time (5-minute intervals) and has built its own internet-based system to read the corresponding data. It has also developed a proprietary algorithm that enables its monitoring system to keep data losses below 5 percent in rural settings, where internet connectivity remains challenging. Husk initially used third-party monitoring systems for benchmarking, but it subsequently discovered that data losses exceeded 20 percent despite these systems, making real-time remote monitoring valueless.

Husk's remote monitoring system measures electrical parameters such as voltage, current, power factor, and frequency. It also measures voltage for the most distant customer to ensure voltage drops do not exceed 10 V. The monitoring system can measure distribution losses in real time, allowing Husk to keep distribution losses below 8 percent.

The system also monitors the time taken to resolve each customer complaint. Preparing for even greater scale, Husk has built a state-of-the-art machine learning–based forecasting system that can manage thousands of sites remotely.

Reliability

Husk prides itself on its service reliability. It averaged 23.5 hours of daily uptime in India in 2020—during the COVID-19 lockdown—when six Discos in Uttar Pradesh and Bihar, two states where Husk operates, averaged only 12–16 hours of daily service (NITI Aayog, Rockefeller Foundation, and Smart Power India 2020, figure 2-17).[36] Discos have poorer service reliability in rural areas, particularly during the summer when they divert electricity to cities, where it is needed more by customers who own air conditioners and pay higher tariffs.

Husk concluded that it would be too costly to increase uptime from 96–97 percent to 99 percent for all customers. It therefore offers close to 99 percent availability only to a small subset of its customers (for example, banks in mini grid communities and hospitals).

Husk's agreements with its Indian customers include a service-level agreement. It has committed to restoring service within 4 hours for households and 2 hours for commercial customers in the event they lodge a service failure complaint. Husk has achieved an average response time of 1.5 hours in India. The company compensates customers if it determines that it was responsible for loss of service.

Financing of appliances and machinery

Husk provides financing for appliance and machinery purchase for both household and business customers. For households and shops, it provides financing for energy-efficient ceiling fans, refrigerators, and LED TVs. For businesses, it finances the purchase of energy-efficient machinery that can be used for productive purposes, for example, equipment used for refrigeration, ice cream production, and rice and maize milling.

Husk has a separate billing system for appliance and machinery purchase. It is not allowed to charge interest on the financing for these purchases because it is not licensed as a bank. Instead, it includes a markup to cover its costs of acquiring and transporting equipment to the mini grid site.

Investment and grant financing

Until the end of 2021, Husk used balance-sheet financing for its mini grids in India. It received US$25 million in Series C equity financing from FMO, Shell Ventures, Swedfund, and ENGIE Rassembleurs d'Energies and US$12.5 million in long-term debt financing, most of which came in local currency in India. Before 2018, it received grants from the Shell Foundation and the United States Agency for International Development's Powering Agriculture: An Energy Grand Challenge for Development program. Since 2013, Husk has not received any government grants for its operations in India. In Nigeria, it has received US$600 per connection for its mini grids. As Husk has demonstrated its ability to scale deployment and operations, its ability to raise debt and equity financing has likewise accelerated. In 2022, Husk raised its first significant debt finance, receiving US$4.2 million in local currency debt from the India Renewable Energy Development Agency Ltd. to build 140 sites in India and US$6 million in debt financing from the European Union's Electrification Financing Initiative to build 80 sites. In July 2023, Husk announced that it had attracted over US$40 million in equity financing and US$60 million in debt financing (Koundal 2023). In September 2023, Husk announced an even more ambitious goal in its Africa Sunshot Initiative (discussed in the later subsection on observations about Nigeria). It declared a 5-year goal of mobilizing US$500 million in debt and equity financing to build 1,000 mini grids in Nigeria, 500 in the Democratic Republic of Congo, and 250 in each of four other African countries to be announced.

On October 24, 2023, Husk announced that it had obtained US$103 million in new financing consisting of US$60 million in debt financing and US$43 million in new equity financing. This is the largest reported mini grid financing package reported to date. The debt financing will come from several financial institutions, including the International Finance Corporation (IFC) and the European Investment Bank. The equity financing will be supplied by STOA Infra & Energy, Proparco, and several earlier Husk equity investors, including FMO, Shell Ventures, and Swedfund. About two-thirds of the financing will be used to build and operate mini grids in Sub-Saharan Africa (principally Nigeria) and one-third in India. Husk projects that this new financing will enable it to build 1,400 new mini grids with a total of 300,000 new connections. About a third of the connections are targeted for MSMEs.

Regulation

Under the Indian Electricity Act of 2003, Husk is not required to obtain licenses or tariff approvals from the central or state electricity regulators. For local rights of way, it usually obtains a no-objection certificate from municipalities.

In India, Husk does not operate as a concessionaire or franchisee of the local Disco. Under Indian law, Discos do not have an exclusive license to their service areas. Therefore, they do not have a legal right to take over Husk's assets. Any takeover of Husk's assets must be by mutual agreement.

Diversification for future viability

Indian state-owned Discos may possibly be able to supply power 24 hours a day at a subsidized rate within the next decade. Husk believes that, even if this were to happen, it could remain commercially viable by doing the following:

- Providing other services, such as clean drinking water and agricultural product processing
- Continuing to sell energy-efficient appliances in the area
- Installing rooftop solar panels for medium enterprises
- Moving mini grid assets to different countries, such as Nigeria.

Husk has taken some initial steps toward diversification in both India and Nigeria. In communities where it operates a mini grid, Husk's business model has expanded from a pure-play mini grid operator to a company that goes beyond just electricity sales by launching energy-service businesses that it owns and operates. In Nigeria, Husk is testing the commercial viability of operating e-mobility businesses, including motorcycle leasing and battery swapping. In both India and Nigeria, Husk is also operating agro-processing hubs, where production from farming collectives is aggregated, processed, and packaged using company-owned machinery. Such services would likely be provided during off-peak hours, increasing the capacity utilization factor.[37]

Additional observations specific to Nigeria

In June 2022, Husk announced the Nigeria Sunshot Initiative, which aims to commission 100 mini grids in the country by 2024 and another 500 by 2026; establish 400,000 connections, which would benefit 2 million people; and take 25,000 diesel and gasoline generators offline. The initiative will include both off-grid and interconnected mini grids.

Husk's first 12 mini grids in Nasarawa state are solar hybrid and off-grid mini grids. They are in communities that have not yet received service from the local Disco (AEDC) (refer to photo 2.13). Husk built a completely new distribution system in every community where it has a mini grid.

Husk's customer base in Nigeria differs somewhat from that in India:

- The customer base in Nigeria has a dominant share of residential households (revenue in India comes predominantly from MSMEs).
- In India, commercial customers tend to use more power at night than MSMEs.
- Customer segments that do not exist in India, such as places of worship and gaming businesses, have potential.
- In Nigeria, residential customers are often farmers, who spend days in their fields cultivating or harvesting. Farming needs in Nigeria might require a different type of pricing package.

PHOTO 2.13

Husk's mini grid in Idadu, Nasarawa state, Nigeria

Source: ©Husk Power. Used with permission; further permission required for reuse.

Husk was able to transfer the knowledge and equipment developed over a decade in India to Nigeria in about a year. The proprietary algorithm used for site selection and demand forecast in India was adopted in Nigeria with slight modification.

Husk reports that the landed cost for panels upon arrival at the port of entry in Nigeria is about 10 percent higher than that in India. Based on initial calculations, it estimates another 25–30 percent addition to costs due to duties, processing, and logistics for moving the panels from the port of entry in Nigeria. These costs mean that CAPEX in Nigeria is higher than in India.

Husk was able to transfer the knowledge and equipment developed over a decade in India to Nigeria in about a year. The proprietary algorithm used for site selection and demand forecast in India was adopted in Nigeria with slight modification. The design and operation of Husk's physical equipment is now essentially the same in the two countries. Husk Nigeria reached the same levels of average revenue per user (more than US$12 per month) after 6 months of operation, whereas it took Husk India more than 3 years.

Husk has leveraged its know-how to establish a complementary business line installing turnkey rooftop solar panels for rural C&I customers within its service areas. In Nigeria, it recently partnered with Hotspot Network Ltd. to convert more than 100 Hotspot-owned mobile telecom towers from diesel to solar. The two companies are also introducing energy and telecom services to mini grid communities as a bundled offering and have already done so in two mini grid villages in Nasarawa state. In addition, Husk is starting to add e-mobility services such as electricity-powered motorcycles in Nigerian villages where it operates mini grids (refer to photo 2.14).

PHOTO 2.14

Ms. Boluwasop Ogboye enjoying e-mobility on an electric motorcycle in Idadu, Nasarawa state, Nigeria

Source: ©Husk Power. Used with permission; further permission required for reuse.

NOTES

1. Appendix B compares the business models adopted or proposed in Nigeria with a very different current business model tested in Uganda's Twaake mini grid pilot. The business models in Nigeria and in Twaake are collaborative in that they require some initial and ongoing cooperation between the mini grids and the Disco (or the main grid–connected utility providing distribution services). We compare the principal features of these business models and provide some initial thoughts on the factors that influence the selection of one business model over another. We are greatly indebted to Sumaya Mahomed (Twaake's former project manager) of Power for All for providing detailed information on the Twaake pilot and for joining us in writing appendix B.
2. Nigeria's mini grid regulations (NERC 2016) require a mini grid to supply electricity to more than one customer and have a total installed capacity not exceeding 1 megawatt (MW). A project does not qualify as a mini grid under these regulations if it serves a single hospital, university, or industrial customer or has an installed capacity over 1 MW; but it could still be classified as a different type of distributed energy resource and receive regulatory approval under other previously approved regulations or guidelines (embedded generation regulation and franchise guidelines). Mini grids are just one type of distributed energy resource.
3. The Rocky Mountain Institute (RMI) is working with Daystar Power to conduct feasibility studies and prepare 20 interconnected projects in Nigeria. This work is being funded by the United States Trade and Development Agency. RMI is exploring ways in which these projects can provide commercial benefits to C&I customers (Sherwood, Tubb, and Olatundi 2022).
4. An RMI study of Nigeria (partly financed by the United States Trade and Development Agency) proposes a business model that is intended to achieve win-win-win outcomes for the existing Disco, C&I customers, and mini grid developers (Sherwood, Tubb, and Olatundi 2022).
5. From the perspective of the C&I customer, the long-term PPA has two advantages. First, it reduces or eliminates the need for the customer to make major up-front capital investments in the mini grid facility. What would otherwise be a capital expense is converted into an operating expense. Second, it allows the developer to concentrate on its core business rather than trying to operate a mini grid for which it lacks the relevant technical expertise. In countries of the Organisation for Economic Co-operation and Development, these arrangements are usually referred to as energy-as-a-service projects.
6. As we were completing the case studies, RMI informed us of the Zawaciki interconnected mini grid in Kano, Northern Nigeria. The Zawaciki mini grid has a combined installed capacity of just under 1 MW and will provide more than 1,600 connections, which will receive power for 10 hours between the hours of 6 pm and 6 am from the Kano Electricity Distribution Company. Bugeja Renewables, the mini grid developer, is promising 16 hours of daily service to its retail customers. The Global Energy Alliance for People and Planet (https://www.energyalliance.org/) is providing the developer with grant financing via RMI. The grant, which is expected to meet 60 percent of the financing requirement, is tied to pre- and postcommissioning milestones. Forty percent of the financing will be with equity. In mid-January 2024, it was reported that the Zawaciki interconnected mini grid was operational and that the Kano Disco wished to build 100 more interconnected mini grids.
7. Based on the business model typology in the Power for All report (Mahomed and others 2020), all five case studies appear to be using the mini grid–led integration model, although integration has yet to take place for the three non-interconnected case studies (Husk, Mokoloki, and Tata).
8. Mokoloki expected to interconnect in the second half of 2023, although the interconnection had not occurred by early December. Husk has announced that it expects to sign interconnection agreements in AEDC's service area before the end of 2023.
9. The case studies in this chapter provide detailed descriptions of specific projects or initiatives of private mini grid developers. In 2016–17, Castalia Advisors prepared detailed case studies that focused on general government programs and specific policy and regulatory actions to promote mini grids in six countries—Bangladesh, Cambodia, India (Uttar Pradesh), Kenya, Nigeria, and Tanzania. The case studies were prepared for the Global Facility for Mini Grids and published by the Energy Sector Management Assistance Program (ESMAP 2022).

10. The original case study and its updates greatly benefited from two RMI Insight Briefs: Graber and others (2019), and Sherwood, Busari, and Okenwa (2022).
11. Commercial customers operate shops; productive-use customers are businesses that use electricity-powered machines. Public institutions consist of schools, clinics, government offices, and churches. Of the 335 customers, 323 are active.
12. Recent World Bank internal survey data suggest that small gensets (0.5 kilovolt-ampere [kVA]) in Nigeria are highly inefficient, producing only 0.25–0.65 kilowatt-hours (kWh)/liter. A quality larger diesel genset typically produces at least 3 kWh/liter.
13. *Smart meter* is a generic term that can cover a wide range of functions, from the basic (prepayment and monitoring of kWh usage) to the more complex (for example, Smart Power India [2019] describes time-of-day tariffs and remote monitoring and control smart meter functionalities in mini grids). For an excellent survey of the use of smart meters in African mini grids, see Mugyenyi and others (2021).
14. Unless otherwise indicated, all conversions are at the June 7, 2021, exchange rate of N413 per US dollar.
15. Direct current coupling solves a problem that arose when large induction loads were creating voltage disturbances severe enough to cause the alternating current–coupled PV inverters to trip offline, depriving the system of some solar electricity.
16. In addition to the Toto project, PowerGen is operating 13 non-interconnected mini grid projects in Niger state, including 6 commissioned in January 2022, in partnership with Nigeria's Rural Electrification Agency and the World Bank. PowerGen's near-term goal is to install 28 mini grids, which will provide power to 55,000 people.
17. Under a new November 2020 tariff-setting system approved by NERC based on different service levels, PowerGen will pay AEDC a price established by NERC for commercial customers receiving electricity at the highest level of reliability (Service Band A). It is anticipated that this tariff will be adjusted every 6 months to reflect changes in exchange rates, grid generation levels, and inflation.
18. The Emir of Toto signed the tripartite agreement on behalf of the community. Local governance conventions differ across Nigeria. PowerGen generally seeks out the person whom the community recognizes as its leader.
19. For a general discussion of regulation by contract, see Brown and others (2006).
20. PowerGen opted to own the meters rather than have the customers own them. It did so to avoid potential complications if, for example, a customer relocates and leaves behind a partially paid-off meter.
21. Mini grids are not the only entities in Nigeria's power sector that receive subsidies. NERC reports that the country's 11 Discos receive operating subsidies from the national government (NERC 2023, table 2.1). Among several subsidies, the national government makes up the shortfall between the amount that the Discos are billed for electricity supplied to them by the National Bulk Electricity Trading company and the smaller amount that the Discos actually pay that company for the electricity. NERC estimates that in 2022 the 11 main grid–connected Discos received a tariff subsidy of slightly over 10 percent per kWh supplied to end users.
22. The Energizing Economies Initiative of Nigeria's Rural Electrification Agency is providing technical assistance to establish mini grids in at least nine other urban marketplaces. Unlike the Wuse project, these projects all plan to operate as electrically isolated mini grids, even though their customers had previously been served by a local Disco. Whether these isolated mini grids will become interconnected mini grids that purchase bulk electricity from the local Discos in the future is unknown.
23. As a gesture of corporate social responsibility, GVE has donated 50 integrated solar streetlights that will improve nighttime ambiance and security around the market. Each streetlight will have its own PV panels and batteries.
24. AEDC will be notified of any end-user tariff adjustments, which are negotiated by GVE and WUMATA and approved by NERC.
25. The parallel market rate had increased to nearly N750/US$1 by December 2022. In June 2023, the Central Bank of Nigeria announced exchange rate unification, which collapses all foreign exchange windows into what is known as the "investors and exporters window" and reintroduces the willing buyer/willing seller model for the pricing of exchange transactions.
26. The government of Nigeria scrapped the fuel subsidy at the end of May 2023. In response, the retail price of petrol almost tripled.

27. About 675 of the more than 20,500 customers are billed on the basis of recorded (that is, postpaid) consumption. Most are high-consumption businesses. TPRMG expects to convert these businesses to prepaid customers by March 2024 so as to eliminate collection risk. Customers also benefit from prepaying, because it allows them to make smaller, planned payments.
28. Parameters include voltage, current, power factor, and active and reactive power.
29. Currency conversions are at the exchange rate of Rs 72.46/US$ (the rate on June 7, 2021).
30. Husk focuses on serving communities, in contrast to the typical business model of focusing on an anchor customer (such as a telecom tower), with community service as a co-benefit. As of August 2023, Husk was exploring mini grid investments in the Democratic Republic of Congo.
31. If gasification has an LCOE that is 30 percent cheaper than battery storage, one might wonder why systems use batteries at all. The reason has to do with partial loads. Loads taper off after 11 pm, but some are still present. Keeping the biomass gasifier running at these times would be inefficient and more expensive than cycling electricity through the battery. During the day, batteries provide a buffer between the production of solar electricity and consumption, without which the electricity supply would be unstable.
32. As a separate business, Husk has sold its proprietary biomass gasification system to rice mills for on-site use. Some rice mills that use the Husk system have reportedly been able to reduce their diesel fuel consumption by up to 60 percent (conversation with Manoj Sinha, Husk's chief executive officer).
33. Husk considers the kWh capacity of its batteries to be commercially sensitive information.
34. The Africa Minigrid Developers Association (AMDA 2022, 16) reported that the average monthly revenue per user of African mini grids by year of commissioning was US$8.60 for 2016, US$9.89 for 2017, and US$10.15 for 2018 but only US$2.19 for 2020.
35. Refer to Trimble and others (2016) for a discussion of six different measures of cost recovery.
36. The Discos' numbers on hours of supply appear to be from 2018 and 2019, so they are not fully comparable with Husk's 2020 numbers.
37. Husk defines the capacity utilization factor for solar PV assets as the actual electricity sold divided by total expected generation based on a PV system simulation using PVSyst™ software. In much of the rest of this document, we refer to the load factor, defined as average kW delivered to customers divided by the peak load (for a discussion of the difference between these two measures, refer to chapter 4).

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3 Regulatory Issues for Undergrid Mini Grids

"Governments throughout the world engage in three main activities: they tax, they spend, and they regulate. Regulation is the least understood. . . ."

—Scott Jacobs, "Building Regulatory Institutions," Organisation for Economic Co-operation and Development, 1994

"Regulation can provide a fertile ground. But regulation does not make a market."

—International Finance Corporation official, World Bank Group Workshop, January 30, 2012

REGULATION: WHAT IS IT?

At its most general level, *regulation* refers to government-imposed controls on business activity. A regulatory system is defined as "the combination of institutions, laws and processes that, taken together, enable a government to exercise formal and informal control over the operating and investment decisions of enterprises..." (Brown and others 2006, 5). The focus of this chapter is on existing and possible regulatory actions that could help or hinder privately owned and operated interconnected and non-interconnected undergrid mini grids that wish to sell to poorly served customers in undergrid areas of existing government-owned or privately owned distribution companies (Discos). Examples are drawn from the national electricity regulator in Nigeria and state electricity regulators in India. Some regulatory decisions are specific to undergrid mini grids; others affect all mini grids (refer to table 3.1). In both countries, numerous other licenses, permits, and approvals are required from government entities other than the electricity regulator.[1]

The focus of this chapter is on existing and possible regulatory actions that could help or hinder privately owned and operated interconnected and non-interconnected undergrid mini grids that wish to sell to poorly served customers in undergrid areas of existing government-owned or privately owned distribution companies (Discos).

A workable mini grid regulatory system designed to support private investment and protect mini grid customers needs to achieve two goals. First, it must convince private mini grid developers (and those who finance them) that the mini grids will be able to recover their costs (including a return on invested capital) and that they will be protected from unexpected changes in government policies and regulatory rules that could lead to de facto or de jure expropriation.

TABLE 3.1 Commercial elements of interconnected and non-interconnected mini grids that could potentially be regulated

	INTERCONNECTED	NON-INTERCONNECTED
Licensing/permitting	✓	✓
Tariffs for retail sales	✓	✓
Recovery of costs to promote productive uses and household uses of electricity	✓	✓
Compensation when the main grid arrives	n.a.	✓
Length of the agreement	✓	✓
Tariffs for bulk purchases by the mini grid	✓	n.a.
Tariffs for bulk sales by the mini grid	✓	n.a.
Rental rate for an existing distribution system	✓	Sometimes
Compensation for energy not supplied by the Disco	✓	n.a.
Compensation if the Disco takes back a subconcession	✓	n.a.

Source: Original table compiled for this publication.
Note: Elements unique to interconnected mini grids are shown in bold. Disco = distribution company; n.a = not applicable.

Second, mini grid customers must be convinced that they will not be left unprotected from any monopoly power that the mini grid has achieved or been granted.

Regulatory processes—the formal and informal procedures regulators use to make their decisions—are especially important for new mini grids, which typically live on the edge of financial viability.

A regulatory system, including both regulatory processes and substantive decisions, needs to be designed to accommodate the characteristics of various mini grid delivery models, including who finances, builds, owns, and operates the mini grid.[2] Regulatory processes—the formal and informal procedures regulators use to make their decisions—are especially important for new mini grids, which typically live on the edge of financial viability. The transaction costs of regulatory processes are as important for commercial viability as the prices the regulator allows. Also, it is not enough to look at formal laws and regulations. The reality is that the formal framework of laws and regulations printed in a government gazette may often not be implemented as written.[3]

KEY POSSIBLE REGULATORY DECISIONS FOR UNDERGRID MINI GRIDS

Table 3.1 presents a list of possible regulatory decisions for both interconnected and non-interconnected undergrid mini grids. The two regulatory decisions that receive the most attention are licensing and retail tariffs, so we will discuss both of these in some detail. In addition, we discuss two other possible regulatory decisions specific to undergrid mini grids that have attracted much less attention—rental charges for the use of a Disco's existing distribution system and compensation if a Disco takes back some or all of a franchise. Both decisions are currently relevant for Nigeria but not India.

One important but often ignored characteristic of regulatory processes is how long it takes for a regulator to issue a permit or approve a tariff. The African Minigrid Developers Association (AMDA), a trade association of private mini grid developers, reports that the average processing time in Sub-Saharan Africa for obtaining all regulatory approvals was over a year. It found that licensing and approval times ranged from 31 weeks in Nigeria to more than 80 weeks in Kenya and Sierra Leone (AMDA, Economic Consulting Associates, and Odyssey Energy Solutions 2022).[4] Governments that are serious about scaling up mini grid development will need to significantly reduce processing times for government approvals.[5]

LICENSING

India and Nigeria have taken very different approaches to licensing. India does not require non-interconnected mini grids in rural areas to obtain licenses or permits. Nigeria requires permits (a streamlined version of full licenses). In contrast to Nigeria, where until recently all economic regulation of the power sector was at the national level, India has regulation at both national and state levels.[6] India's constitution specifies that electricity sector regulation is a "concurrent" subject, meaning that every state implements "state-specific regulation within a broad national framework" (Palit, Graber, and Sherwood 2020).

For mini grids, the most important national law in India is the Electricity Act, 2003, which mandates the deregulation or "de-licensing" of rural mini grids and prohibits state electricity regulatory commissions (SERCs) from requiring licenses for mini grids. SERCs have the legal authority to set tariffs only for licensed entities; therefore, the law effectively deregulates the tariffs that mini grids can charge their retail customers. In effect, the regulation is a blanket prohibition on licensing and tariff regulation for rural mini grids as opposed to the size-differentiated regulation that exists in Nigeria and other Sub-Saharan African countries. Mini grid developers in India are also not required to obtain formal approval from the Disco licensed to serve a community or from the community itself, which means that a Disco does not have veto power over the entry of a new mini grid in its service area.

The Nigerian Electricity Regulatory Commission (NERC) set forth two regulatory processes for market entry of isolated mini grids: registration and permitting. A third option, licensing, applies to entities that are larger than 1 megawatt (MW) (NERC's current regulations prohibit mini grids from having an installed capacity greater than 1 MW, so licenses are not a relevant option for mini grids). If a mini grid has an installed capacity of 100 kilowatts (kW) or less, it is allowed to register with NERC.[7] Registration does not require NERC approval; the government uses the application for information purposes only. A mini grid developer that decides to register provides NERC with only some basic information (legal status of the applicant, description of the project, expected number of customers, and expected tariff). A downside of registration from the mini grid's perspective is that the mini grid loses the right to compensation or conversion to another business model if the Disco decides to extend its grid to the community served by the mini grid.

Mini grids below 100 kW do have the option to seek a permit, which gives them additional property rights after interconnection. To obtain a permit, a mini grid (whether above or below 100 kW) needs the approval of the local Disco in an unserved area. The Disco must state that the proposed mini grid "will not interfere with the expansion plans in the designated Unserved Area" (Section 7 (1)(b)) or provide written consent if the mini grid developer is proposing a project that "will be within the five-year expansion plan of the Distribution Licensee" (Section 7 (1)(c)) (NERC 2016). In addition, the mini grid developer must obtain the written approval of the community it proposes to serve, using the model contract template (annex 12 in the 2016 mini grid regulations) developed by NERC. In its 2023 mini grid regulations, NERC changed its regulations to state that the Disco is deemed to have given its approval if it fails to act within 15 days of receiving a request for approval from a mini grid developer (NERC 2023, Section 7.2).

NERC regulations define mini grids as being isolated or interconnected and having up to 1 MW in generation capacity; electricity supply projects above 1 MW do not qualify as mini grids under current regulations. However, these larger generation and distribution systems have another regulatory option—applying to NERC under a different set of regulations known as the "embedded generation" regulations (NERC 2012). These regulations, dating from 2012, require two approvals. The first is for a generation license, which is not required for mini grids of less than 1 MW. If awarded an embedded generation license, the licensee would be allowed to inject up to 20 MW of generation into a specified area of the Disco's franchise area. The second approval for the embedded generation license comes with an additional restriction: under current NERC regulations, the license holder is allowed to generate and sell power to just a single buyer. In contrast, mini grids limited to 1 MW or less can serve multiple customers. If the developer wants to serve more than one buyer, it can apply to NERC for approval of a separate subfranchising agreement with the Disco to assume the supply of electricity within a ring-fenced distribution area or on specific distribution feeders.[8] The benefit of the subfranchising agreement is that it allows the developer to serve multiple customers within the specified distribution area. A different and simpler regulatory solution would be to increase the 1 MW ceiling in the current NERC mini grid regulations to 3 or 5 MW. If a larger (above 1 MW) system is categorized as a mini grid, it would be allowed to serve multiple customers without further regulatory approvals.

LICENSES VERSUS CONCESSIONS

Licenses and concessions are legal instruments that share some features. Both grant the recipient the right to provide one or more services at a specified geographic location or in a service area for a defined period of time on either an exclusive or nonexclusive basis. Both specify regulatory requirements, usually including the maximum tariffs that can be charged and the minimum technical and commercial characteristics of the service.

A license is not a contract between the regulator and the mini grid developer; instead, it is a government authorization to provide a service.

Licenses and concessions also differ in important ways. A concession is a contract between a high-level entity within the government (usually a ministry) and a private provider of a service. The ministry representing the government is a signatory (counterparty) to the contract. A license is not a contract between the regulator and the mini grid developer; instead, it is a government authorization to provide a service.[9]

Concessions are broad; licenses are narrow. Concessions specify obligations and responsibilities of both the government and the mini grid company. Licenses specify the rights and obligations of the mini grid operator but usually are silent about the rights and obligations of the government. In contrast, a concession agreement usually contains regulatory provisions (for example, maximum average tariffs and minimum technical and commercial service requirements), as well as the terms and conditions of government grants to mini grids, protections against expropriation, and changes in tax and other laws. A concession contract can be thought of as an umbrella contract that typically covers most major government actions that could affect a mini grid's revenues and costs. Box 3.1 describes some early mini grid concessions in Sub-Saharan Africa.

If there is a dispute over how the concession's terms and conditions have been implemented, the concession agreement usually requires that the government

BOX 3.1

Early mini grid concessions in Africa

Hosier and others (2017) describe six early mini grid concessions in Sub-Saharan Africa. Five are in civil law countries (Burkina Faso, Guinea, Madagascar, Mali, and Senegal) and one in a common law country (Uganda).

The mini grids were developed in response to government-issued general expressions of interest rather than as formal competitive tenders. Most of the concessions were awarded on a project-by-project basis to local entrepreneurs. These concessions generated little or no interest from foreign firms.

Of the six countries, Mali had the most success. About 250 mini grids were established, providing an estimated 78,000 connections. Hosier and others describe these mini grids as "spontaneous local proposals" with no connection to a formal government planning process. The mini grids were promoted by AMADER (Agence Malienne pour l'Energie Domestique et de l'Electrification Rurale [Malian Agency for Domestic Energy and Rural Electrification]), Mali's rural electrification agency, which acted as the regulator as well as the provider of capital cost grants. As of this writing, zonal mini grid concessions are being developed in the Democratic Republic of Congo. Government interest in establishing some form of modified concessions for groups of mini grids that would also attract foreign investors in civil and common law countries in Africa is not clear.

and the concession holder submit to some form of arbitration that operates outside of the country's court system. In contrast, if a mini grid license holder is dissatisfied with the regulator's implementation of its license, the license holder is typically required to take its complaint to a domestic appeals court rather than to an outside arbitrator.

Concessions generally do not support full privatization. Instead, at the end of the concession period, the entity that has been awarded a concession is usually required to hand over all its assets to the government entity that awarded the concession. The concession agreement will specify a formula or principles for calculating the economic compensation the concessionaire will receive for the transferred assets. In contrast, licenses can support full privatization, because there is typically no obligation to hand over the assets to a government entity at the end of the license term.

A ministry might want to issue a concession for several reasons. One would be to back up the terms and conditions in a mini grid license or permit already issued by the national electricity regulator. A concession gives mini grid investors more certainty that the regulator will implement the rules as written, especially if it is backed up by a breach-of-contract insurance policy issued by the World Bank Group's Multilateral Investment Guarantee Agency or some other insuring entity (refer to appendix H). Because a concession is backed by a government with a contractual commitment and may be eligible for breach-of-contract insurance offered by a third party, a concession contract may help mini grid developers obtain loans with lower interest rates and longer terms.

Because a concession is backed by a government with a contractual commitment and may be eligible for breach-of-contract insurance, a concession contract may help mini grid developers obtain loans with lower interest rates and longer terms.

A concession contract can include commitments beyond just backing up the national regulator's rules and decisions. These commitments could include grants for connections, protection against changes in tax and other laws, and the right to convert revenues earned in the local currency to foreign currencies. These additional commitments will improve the bankability of mini grid projects.

RETAIL TARIFFS

Regulators around the world face a dilemma in deciding how to regulate mini grid tariffs. Their regulatory statutes typically require that they must protect mini grid customers from monopoly prices. Although high prices are not necessarily monopoly prices, prices that are higher than main grid retail prices, whether cost-justified or not, may attract opposition from government officials and politicians (refer to box 3.2)—even though setting tariffs too low hurts the very people who would benefit from the mini grids.

India's Electricity Act, 2003, prohibits SERCs from requiring private mini grids in designated rural areas to obtain a license, and SERCs are not allowed to set prices for unlicensed entities; retail tariffs charged by mini grids are therefore effectively deregulated in India.

India's Electricity Act, 2003, prohibits SERCs from requiring private mini grids in designated rural areas to obtain a license, and SERCs are not allowed to set prices for unlicensed entities; retail tariffs charged by mini grids are therefore effectively deregulated in India. A privately owned and operated mini grid can charge tariffs to consumers on a mutually agreed upon basis (a "willing buyer/willing seller" approach to tariff setting).

This approach disappears if a mini grid accepts a subsidy from a state government. In Uttar Pradesh, the state government issued a mini grid policy in 2016 that offered a 30 percent capital cost grant to renewable mini grids of up to 500 kW capacity that offered to serve "remote and economically weaker areas." In return for receiving this grant, the mini grid operator had to agree to provide 8 hours of daily service at an unrealistically low regulated tariff.[10] If this offer had been accepted, the state's grant-giving agency would have become the de facto tariff regulator.[11] In the 7 years since the policy was announced, no mini grid developer has accepted the state's offer of a capital cost grant because the low mandated tariffs would not be commercially viable even with the grant.

In Nigeria, retail tariffs of all mini grids with more than 100 kW of installed generating capacity must be approved by NERC. NERC conducts a separate tariff review for each proposed mini grid project, based on a prespecified, cost-of-service methodology known as the mini grid multiyear tariff order (MYTO).[12]

BOX 3.2

The politics of mini grid tariffs

> "Remember that the end user is both a consumer and a voter."
>
> —Morgan Landy,
> International Finance Corporation,
> World Bank Energy Day, 2012

When a village or town is first connected to a mini grid, there is widespread excitement and satisfaction. Ribbon-cutting ceremonies are held. Businesses soon realize that they can get rid of expensive, noisy, and polluting diesel generators. And households appreciate that they now have a reliable electricity supply during critical evening hours. Some have likened the first year to a honeymoon period. The honeymoon glow begins to fade when customers start questioning the reasonableness of the mini grid's tariffs.

After a year or two, a conversation between a government rural electrification official and donor-hired consultant might go something like this:

Government rural electrification official:

> OK, I understand that no one forces a household to become a customer of the mini grids. They did it voluntarily because they saw that it was to their benefit. They are paying less overall for energy than before and are getting electricity with higher reliability. But there is still a

(Box continues on next page)

Box 3.2. The politics of mini grid tariffs *(continued)*

problem. You told me that your organization and other international agencies like the International Energy Agency and World Bank have performed detailed studies that show that mini grids are the nation's least-cost solution for scaling up access in many locations. And that is what I told the energy minister.

But now what do I say when I get a call from a member of parliament who wants to know why the regulator approved a mini grid tariff in his district that is two to three times higher than the tariff paid by residents of a neighboring village served by the national utility or a distribution company connected to the national utility? And the member of parliament is even more suspicious because he has also heard that the private mini grid developer received a government grant of US$600 for each new customer that he has signed up. He points out that the mini grid developer still charges a much higher tariff than the national utility even with this subsidy. Just before the call ended, the member of parliament accused me of not doing my job!

International consultant hired by donors:

You need to tell the member of parliament that the reason why the national utility is charging lower tariffs than the mini grid is that the national utility is not charging cost-recovering tariffs. Please remind the minister that the national utility or local Disco gets all kinds of direct and indirect subsidies from the government. So, you can't just compare the two tariffs. And also point out to the member of parliament that the mini grid is providing a much more reliable service. Any simple comparison of the two tariffs that doesn't take into account the major differences in reliability will be an apples-to-oranges comparison. You need to mention that the mini grid has to cover all its costs from revenues. And that is not true for the government-owned utility. Because it has the government as a financial backstop (though not always a reliable one), it doesn't have to cover all its costs in the tariffs it charges.

Government rural electrification official:

Look, I think that you are still missing the point. People in the village are not interested in hearing a lengthy and nuanced economic analysis as to which supplier, the national utility or the mini grid, is getting a larger subsidy. Instead, the villagers focus only on what they pay for electricity and how the prices they pay compare to the prices paid by friends and relatives in villages served by the national utility. They say, "It is not fair that I'm being charged a higher price." And I think I need to remind you of an obvious point: no candidate for parliament ever gets elected on a platform that the national utility or the government-owned distribution company should be forced to charge fully cost-recovering tariffs.

The problem with this conversation is that the government official and international consultant are talking past each other. The fact that mini grid–supplied electricity is the least-cost economic option from a national planning perspective does not mean that it will be viewed as the least-cost option by households supplied by the mini grid. If households know that they are paying more for mini grid electricity than other rural households served by the national utility, they are not going to be persuaded that their higher tariffs somehow serve the abstract national interest of least-cost planning. That explanation might appeal to technocrats, but not to villagers.

The templates for NERC's MYTO methodology are spreadsheets that can be downloaded from the NERC website (www.nerc.gov.ng). Mini grid developers fill in the spreadsheets with their estimates of capital expenses (CAPEX), operating expenses (OPEX), subsidies, expected consumption by different customer categories, and payments to and from the Disco (in the case of an interconnected mini grid). Developers can work offline before uploading the completed spreadsheets in the package of documents submitted to NERC.

The MYTO methodology is a standard cost-of-service or revenue-requirements approach to setting tariffs. It calculates separate tariffs for each year of a 5-year tariff period, although most mini grid developers request a single tariff that, if approved by NERC, stays in effect for the full 5 years.

The mini grid developer may ask for approval of tariffs below the cost-justified tariffs calculated by the MYTO methodology (see the Mokoloki and Toto case studies in chapter 2) in order to avoid tariff shock and political backlash (refer to box 3.2). The developers appear willing to absorb losses in the early years of operation in the hope of earning profits in later years if the number of customers and average consumption levels of customers increase (see appendix I).

It has been reported that NERC and Nigeria's Rural Electrification Agency (REA) have informally conveyed the message that tariffs in the range of 200–300 Nigerian naira, or N (US$0.484–US$0.726) would not be acceptable even if they are justified by the MYTO method. Several other African countries have also set unofficial caps.[13]

Three other features of Nigeria's MYTO tariff-setting system are worth highlighting:[14]

1. **Performance-related profit margin**. All mini grids are allowed to include a performance-related profit margin in their MYTO calculated tariffs. Under traditional individualized cost-of-service regulation, a mini grid developer's profits depend on the size of the regulatory asset base (also referred to as the "rate base"). If the developer received significant capital cost grants, the regulatory asset base and allowed profits will be small. The mini grid developer will be allowed to cover only operating expenses, with very little compensation for developing and operating the project. The performance-related profit margin (currently set at N8 [US$0.019] per kilowatt hour [kWh]) allows developers to earn a profit in addition to their operating expenses when there is a small regulatory asset base.
2. **Depreciation annuity**. NERC uses an annuity approach to calculate the depreciation component of the tariff. If a traditional cost-of-service approach were to be applied to a new mini grid project, it would lead to high depreciation charges and high tariffs in a project's early years and tariff spikes when assets are replaced. To avoid tariff shock, NERC has adopted an annuity approach to calculating depreciation, which keeps the combination of the depreciation charge plus the return on the regulatory asset base fixed for the lifetime of the assets, resulting in a constant tariff in case of constant demand and OPEX.
3. **Fixed tariff with some adjustments.** The tariff is fixed for 5 years except for adjustment in some components of operating expenses (for example, salaries, diesel fuel, and maintenance expenses) based on projected inflation as well as adjustments based on projected changes in the demand. These adjustments cannot be made unilaterally by the mini grid operator; they go into effect only with the agreement of the community.

ALTERNATIVES TO INDIVIDUALIZED COST-OF-SERVICE REVIEWS

The dominant tariff-setting approach for mini grids chosen by NERC and regulators in Kenya, Rwanda, Sierra Leone, Tanzania, and Zambia is based on individualized cost-of-service calculations. Under this approach, the regulator sets limits on individual tariffs for each mini grid based on a full cost-of-service analysis for each mini grid. The cost-of-service analysis is designed so that the mini grid owner can recover its OPEX, depreciation on its assets, and a rate of return based on the cost of debt and an allowed return on equity. In Nigeria, the MYTO system for mini grids is similar to the cost-of-service approach that NERC uses in setting retail tariffs for Nigeria's 11 Discos.

Cost-of-service regulation has two weaknesses. First, the mini grid's incurred costs may not be efficient costs. The fact that a cost appears on an invoice is no guarantee that it is efficient. Second, individual cost-of-service reviews are not administratively practical in a country like Nigeria, which hopes to create hundreds or thousands of mini grids.

Individualized tariff-setting based on cost of service imposes considerable transaction costs on both the regulator and the developers. This practice will lead to delays in processing tariff applications and mini grid investments. The regulator is not protecting consumers if regulatory processes are slow and prevent consumers from being served by lower-cost, more reliable, and less polluting options.

Individualized tariff-setting based on cost of service imposes considerable transactions costs on both the regulator and the developers.

Two alternatives to individualized cost-of-service calculations are available, as described in the following subsections.

Alternative 1: Willing buyer/willing seller

In the willing buyer/willing seller model, the tariff is set at a price that the mini grid developer and its customers agree on; the tariff does not require prior approval by the regulator. This approach has been legally mandated for all non-interconnected rural mini grids in India since 2003.

In Nigeria and Tanzania, the willing buyer/willing seller approach is used in a more limited way. In both countries, the national regulator accepts the price the developer and consumers agree on if the mini grid's generating capacity is less than 100 kW. This practice has been referred to as "tiered regulation" (AESG 2021). The willing buyer/willing seller approach does not mean that the mini grid developer negotiates a separate tariff with each customer. The developer typically offers a prespecified tariff on a take-it-or-leave-it basis to all customers in a customer class (residential, commercial, institutional, and small industrial); however, the mini grid operator will not have total freedom in setting tariffs. The operator's ability to set high prices will be limited by the disposable income of households, the availability of traditional energy sources, and the customer's ability to purchase electricity from a Disco connected to the main grid.

This approach is practical, because the regulator would be overwhelmed if it had to make a cost-of-service calculation for each of hundreds of very small isolated mini grids. From the developer's perspective, the cost of putting together a tariff application could easily destroy the commercial viability of a mini grid system of less than 100 kW. The exemption from regulatory approval of tariffs may also create an incentive for developers to size their projects at less than 100 kW even if a larger grid would be more efficient and have lower unit costs.

Regulators have adopted the willing buyer/willing seller tariff-setting approach in other circumstances in both developed and developing countries. For example, commercial and industrial (C&I) customers will typically enter into negotiated long-term power purchase agreements with mini grid developers. A big advantage of a long-term power purchase agreement for a commercial or industrial customer is that the customer need not come up with the capital necessary to build the mini grid but still has the possible backstop of building and operating its own generation if the prices charged by the developer should become too high.

Alternative 2: Soft benchmarking of retail tariffs

Benchmarking requires comparing either costs or prices across a group of comparable mini grids and typically involves setting a price cap based on the observed average cost of a number of comparable projects or possibly an estimate of the costs of an efficient project.

Regulators sometimes use price benchmarking if they are required to regulate the prices of a large number of comparable entities. In such situations, it is simply not practical for a regulator to devote its limited resources to setting tariffs for hundreds or thousands of mini grids on an individual cost-of-service basis.[15]

A hard benchmark means that the regulator will reject tariff requests above the benchmark price cap. A soft benchmark is different. It means that the regulator is saying:

> I have systematically gathered information on projects that are comparable to yours. Based on my review of these projects, here is a price cap that I believe will cover your costs and allow you to earn a reasonable profit if you build and operate with average efficiency. If you request approval for a tariff that is equal to or below the price cap, the approval will be fast-tracked and approved within a short period of time. But the soft benchmark does not prevent you from asking for a higher tariff. If you think that your project's circumstances are unique because you have higher costs that are beyond your control, feel free to request a higher tariff and I will review it. But you should recognize that I will need to take a close look at your cost and operating data, so the review process will take longer.

If soft benchmarking is going to work for mini grids, the regulator must do several things. To start with, it must collect information on the CAPEX and OPEX of different mini grid projects and approved tariffs and make this information public on a periodic basis. NERC, for example, collects detailed cost information from the MYTO applications it receives from mini grid developers seeking approval for permits and retail tariffs. Its staff creates tables showing the costs of different mini grid projects as well as the costs of individual components (meters, photovoltaic panels, transformers). It would be useful to developers if NERC made these tables (with identifying data removed) publicly available.[16]

A more controversial form of benchmarking would be to make public a table showing the allowed tariffs of approved mini grid projects. Publishing approved mini grid tariffs would give communities without mini grids a sense of the tariffs being paid in other communities, thus reducing the information asymmetry between developers and communities.[17] It could also lead to angry complaints by early adopter communities that would want the lower tariffs paid by later-adopting communities.

If NERC decided to put information about proposed or charged mini grid tariffs in the public domain, it could use the online "Mini-Grid Monitor Dashboard" that was launched by the Ministry of Power with the support of the Sustainable Energy for All program in 2019. This portal (https://nigeriase4all.gov.ng/mini-grids) provides a live map showing the locations of all proposed and operating mini grids in the country. It should be relatively easy to add information to the dashboard on the retail tariffs of individual and groups of interconnected and non-interconnected mini grids.

Most mini grid developers in Africa and India seem opposed to putting information about their tariffs in the national public domain, for three reasons.

First, they are afraid that their tariffs will become a political football, with legislators complaining that the mini grid's tariffs are higher than the tariffs charged by the main grid or Discos.[18] (Box 3.3 provides an example of the drastically lowered mini grid tariffs ordered by the Ministry of Power in Tanzania just before the 2020 presidential elections.) These complaints typically ignore the fact that the mini grid provides a much more reliable and higher-quality service than the grid.

Second, making tariff information public increases the likelihood that potential or existing customers will complain to the regulator if their tariffs are higher than the tariffs in other towns or villages served by other mini grids, even if there are cost justifications for the higher tariffs charged in their village. These complaints could lead to lengthy and expensive regulatory reviews by NERC.

Third, if developers ask for lower tariffs to get a foot in the door, once these non-cost-recovering tariffs become public, they could become de facto price ceilings for all future mini grid projects, which would discourage developers. The bottom line is that most mini grid developers are opposed to publicizing their tariffs, at least in the early stages of development.

Mini grid developers' concerns are understandable. If, however, mini grid retail tariffs are not publicized, developers and regulators will be vulnerable to accusations that they have entered into a conspiracy to block the government and consumers from knowing what tariffs are being charged around the country. The perception of a conspiracy carries the risk that nonpublished tariffs would be overturned by parliament or a minister, especially before an election.

Regulators wishing to use soft benchmarking for mini grids must also (1) report benchmarked data by the year of approval; (2) distinguish between

Most mini grid developers in Africa and India seem opposed to putting information about their tariffs in the national public domain . . . .

BOX 3.3

Overriding mini grid tariffs approved by the regulator in Tanzania

In the World Bank's 2020 *Regulatory Indicators for Sustainable Energy* (https://rise.esmap.org/reports), Tanzania received a high score of 80 points for its mini grid regulatory and policy framework. In July 2020, however, 4 months before Tanzania's presidential election, its Energy and Water Utilities Regulatory Agency (the national electricity regulator), under orders from the minister for energy, issued a four-line directive that gutted the tariff-setting method the agency had approved in its 2019 mini grid rules. The agency's new directive mandated that mini grid operators reduce their tariffs to the same levels charged by the Tanzania Electric Supply Company Limited, the government-owned national utility. Because most mini grid customers were small residential customers, this mandate meant that mini grid operators were now required to charge the utility's D1 tariff of US$0.043 per kilowatt-hour. Doing so meant that mini grid operators were forced to reduce their tariffs by 75–97 percent. If this tariff order is not reversed, it is likely that most existing mini grid operators will go out of business or greatly reduce their hours of service.

The gap between a formal written regulatory framework and the way that framework is implemented is not limited to mini grids. In a comprehensive survey of power sector reform, Foster and Rana (2020, 202) conclude that there are often "sizable discrepancies between the quality of formal (de jure) regulatory frameworks and the extent to which those frameworks are perceived to operate in practice" for the entire power sector. A ranking of regulatory systems based simply on an evaluation of the formal written regulatory regime will often not be a good predictor of how the tariff-setting regime will be implemented when the regulator comes under strong pressure from political authorities.

isolated and connected mini grids; and (3) benchmark nationally, rather than on an Africa-wide basis.

- The costs of photovoltaic panels and batteries have fallen. Cost comparisons should therefore be distinguished by the year a project becomes operational. Alternatively, the regulator could reduce the soft price cap by a prespecified percentage every year to recognize the downward trend in mini grid costs until there is evidence of cost stability or an upward trend.
- The cost structures of isolated and interconnected mini grids will differ (refer to chapter 4). Information on their costs and tariffs should therefore be reported in separate benchmarks. NERC and the REA routinely collect information on the costs of traditional isolated mini grids. In a few years, similar information may be available for interconnected mini grids. Within the category of interconnected mini grids, it would be helpful to distinguish between projects that have a firm bulk supply commitment from their local Disco and those that do not.
- Wide variations exist in mini grid costs across Africa and Asia, reflecting differences in the buying power of mini grid developers in different countries as well as differences in taxes and import costs. Until better data are available on how taxes and import costs vary across countries, cross-country comparisons will not be useful.

APPROVING PORTFOLIOS OF PROJECTS

Another way for regulators to use their limited regulatory resources more efficiently is to approve portfolios of projects rather than single projects.

Another way for regulators to use their limited regulatory resources more efficiently is to approve portfolios of projects rather than single projects.[19] In Nigeria, the REA has created four portfolios of mini grid projects consisting of an average of 35 projects at preselected sites in each portfolio. When a request for proposals was issued, potential developers were asked to bid a minimum required subsidy per connection for all projects in a portfolio.[20]

NERC could support the REA's portfolio approach by changing its permitting process. One approach would be to issue a single permit for all the projects in the portfolio rather than requiring the winning developer to apply for a separate permit for each mini grid in the portfolio. The regulator in Sierra Leone already uses a portfolio approach in approving both mini grid licenses and tariffs. Uganda's mini grid regulations allow a mini grid developer to "submit one application for multiple isolated grid systems within the same geographical location" if the total generation capacity of all the isolated systems does not exceed 2 MW.

In Nigeria, if a single permit is not legally permissible because the installed capacity of the portfolio of projects would exceed the current 1 MW ceiling in NERC regulations, NERC might be able to issue a generic permit; developers would then be required to affirm their acceptance of the terms and conditions of the permit for all projects in the initial portfolio. If a new project is later developed, the developer could be required to affirm that it would use the same technology and ask the regulator to apply the generic permit to it. Presumably, the generic permit would include a regularly updated annex listing all projects operating under the permit. If the regulator did not ask for additional information, a new project could be deemed to have been issued the generic permit after the passage of a set period of time (for example, 20–30 days).

A second possible approach for Nigeria would be to continue issuing permits to individual mini grid projects to satisfy the 1 MW ceiling but to allow a single application and a single tariff for a portfolio of projects (as Sierra Leone and

Uganda do). The application would be on behalf of all the projects in the portfolio that use the same technology.

In August 2022, NERC proposed a variant of this change for public comment. The proposed change would allow a developer to make a single application for a portfolio of mini grids as long as the individual mini grids in the portfolio are no more than 80 kilometers from each other. NERC also proposed that a developer should be able to submit a single annual combined report for all the mini grids in its portfolio.

Another potentially useful action would be to approve a single set of tariffs for all comparable projects in a portfolio rather than separate tariffs for each project. Such a move should not be limited to portfolios of projects built through a government-sponsored competitive procurement (for example, Nigeria's minimum-subsidy tender). The regulator should also have the option of approving a single tariff ceiling for a portfolio of similar projects created by developers outside a government-sponsored competitive procurement.[21]

In Nigeria, mini grid developers are beginning to cluster projects to gain construction and operating efficiencies that will lead to lower costs (refer to the Husk Power case study in chapter 2). NERC could encourage this trend by accepting a single tariff application for projects in the portfolio, even though each project will be granted a separate permit. In its August 2022 public consultation, NERC proposed that "an applicant may submit a single tariff application for the entire portfolio or individual tariff applications for each under the Portfolio" (NERC 2022). In its 2023 regulations, NERC stated that it would allow mini grid developers to apply for a single permit and a single tariff for a portfolio of proposed mini grid projects (NERC 2023, Sections 3 and 22.4.a).

TWO OTHER REGULATORY ISSUES FOR UNDERGRID MINI GRIDS

Two other possible regulatory decisions specific to undergrid mini grids have attracted much less attention—rental charges for the use of a Disco's existing distribution system and compensation if a Disco takes back some or all of a franchise. Both decisions are currently relevant for Nigeria but not India.

Charges for the use of the distribution system

It is unrealistic to expect that a Disco will offer the use of its distribution system to a mini grid out of goodwill. Discos need to be given financial incentives to interconnect. As seen in the Toto and Wuse case studies, the two most likely sources of additional revenue are mini grid payments to lease the Disco's existing distribution system and payments for bulk purchases of electricity by the mini grid from the Disco.

In Nigeria, interconnected mini grids pay what is known as a Distribution Use of System (DUOS) charge for the right to use the Disco's distribution system. By paying the charge, the mini grid operator receives "an exclusive right of usage, operation, maintenance, management and control of the Interconnected Network for the duration of the Term" (NERC 2016, annex 8). It is anticipated that the DUOS payments will be in the range of US$0.01–US$0.03/kWh sold to the mini grid's retail customers.[22] The DUOS payment could also be a fixed monthly fee.

For the first six proposed interconnected mini grids in Nigeria's Interconnected Mini-grid Acceleration Scheme, or IMAS (refer to appendix I), it is estimated that the DUOS charges would provide an average of US$11,205 in annual revenue to the six Discos. The DUOS payments are projected to come to about 18 percent, on average, of a mini grid's operating expenses.

The second source of revenue, payments for the purchase of bulk electricity, is roughly equivalent. For the same six interconnected mini grids, it is estimated that, on average, a mini grid will pay US$9,841 a year for electricity from the local Disco. These mini grids are relatively larger. Under IMAS, each of the six projects must have a minimum of 1,500 connections with a projected average of 2,306.

One interpretation of the DUOS charge is that it is a payment by the mini grid for the right to use Disco distribution facilities that are in usable condition. A second is that it is a payment for the right to use all the Disco's infrastructure, whether it is usable or not, during the subconcession period. The portion of the distribution grid that is usable can vary widely. In the case of the six proposed mini grids, developers estimate that only about 10–45 percent of the grid is usable. Current NERC rules require that the Disco and the mini grid owner must agree on the portion of the existing grid that is usable as a condition for NERC's approval of the tripartite agreement.

Under either interpretation, the key question regards the appropriate level for the DUOS if the Disco and the mini grid cannot agree. NERC does not mandate a specific approach to calculating the DUOS. Instead, the Disco and the mini grid are urged to negotiate a price. If the two parties are unable to agree on a price, NERC (2016, annex 8) recommends the following recourse:

> The basis for calculation shall be the lost profit of the Distribution Licensee from electricity sales within the part of the distribution network hired out to the Mini-Grid Operator. The usage charge shall be calculated based on the average profit generated by the Distribution Licensee within the last 12 months plus any operation and maintenance costs that are not transferred from the Distribution Licensee to the Mini-Grid Operator.

The problem with this approach is that most Discos will not have an incentive to hand over profitable areas to mini grid developers; instead, they will have a strong incentive to offload loss-making areas. NERC recognizes that in most instances the Disco will have suffered negative profits on the assets to be hired out to the mini grid operator. In this situation, NERC suggests that "the parties shall consider a hiring arrangement without any compensation, at least for a certain period of time (for example, 5 years)" (NERC 2016, annex 8).

This advice reduces or eliminates a Disco's incentive to offer its distribution assets to the mini grid operator. A better alternative would be to require the starting point for determining the DUOS payment to be the carrying charges on the depreciated value of the Disco's usable distribution assets. This starting point would still require an adjustment. The fact that distribution assets remain on the books with a depreciated value is no guarantee that they are in usable condition. Therefore, we recommend that a floor for the DUOS value be established as the product of the carrying charges on its depreciated value and the percentage of the assets designated as usable in the tripartite agreement filing. NERC should still encourage a negotiated agreement for DUOS charges, but it could use this rule as a backstop if the two parties fail to agree. This approach is reportedly under consideration by NERC in cases when the Disco and the mini grid cannot agree on a negotiated DUOS value.

Compensation for Disco takeovers of mini grid assets

The principal rationale for specifying compensation rules in mini grid regulations is the presumption that potential investors in isolated (typically rural) mini grids will not invest in mini grid projects if there is a high risk that the main grid will arrive sooner than expected. If this happens, mini grid owners may never be able to recoup their investments. A 2015 survey of potential private mini grid developers in India by researchers at Stanford University found that this risk was a major concern. The study concludes that the threat of main grid extension was the single biggest deterrent to making mini grid investments (Comello and others 2015).

What can regulators can do to ensure that mini grid developers have an incentive to invest in new mini projects if there is a real possibility that the Disco will arrive sooner than expected and be able to provide service to the same town and village at prices lower than the mini grid's tariffs? The general presumption is that regulators need to specify some form of compensation to the mini grid owner for any distribution assets that will be taken over or made worthless by the arrival of the Disco or some other main grid entity at some early date.[23] In designing a compensation mechanism, the two key implementation questions ask which events trigger compensation and how much the mini grid owner will be paid.

In Sub-Saharan Africa, most new mini grid regulations specify that the owner of an isolated mini grid system that has received a basic license or a permit to provide electricity service in an unserved area is entitled to compensation if the Disco arrives earlier than agreed to or expected, but we do not know of any African mini grids that have actually received compensation under any of these rules.[24] In Nigeria, a previously isolated mini grid that has received a permit from the regulator is given the option of either converting to an interconnected mini grid or receiving compensation for all assets it chooses not to remove. The compensation is equal to the "remaining depreciated value of assets (including the construction and the development cost)" plus the revenue received by the mini grid operator during the previous 12-month period (NERC 2016, Section 19 (2)). Compensation for construction and development costs is granted only if the takeover occurs less than 5 years after the mini grid becomes operational.[25]

In Sub-Saharan Africa, most new mini grid regulations specify that the owner of an isolated mini grid system that has received a basic license or a permit to provide electricity service in an unserved area is entitled to compensation if the Disco arrives earlier than agreed to or expected, but we do not know of any African mini grids that have actually received compensation under any of these rules.

Sierra Leone's mini grid regulations specify essentially the same compensation formula as Nigeria's regulations, on which they draw heavily. Tanzania's regulations specify a different approach. Its compensation formula is not based on the value of the mini grid's depreciated assets and revenues earned but rather on a recent measure adopted by Tanzania's Rural Electrification Agency of capital costs incurred for "installing distribution equipment in rural areas" (EWURA 2019, Section 49 (9a)).

Most Discos and REAs in Sub-Saharan Africa do not have the money to buy out isolated mini grids. Donor funding provides grants for main grid utilities to build new distribution facilities but few or no financial incentives to take over and provide compensation for mini grid distribution assets. Funds to expand access usually come in the form of grants or concessional loans from donors like the African Development Bank, German Agency for International Cooperation (GIZ), Norwegian Agency for Development Cooperation, and World Bank.

Under current grant programs, the utility or the REA is paid for each connection and portion of the transmission and distribution network. Integrated utilities and Discos do not receive money to buy out an existing mini grid connection, and they are not penalized for rolling over existing infrastructure.

Jessica Stephens, former chief executive officer of AMDA, points out that utilities "are essentially incentivized to build over existing infrastructure, which has made interconnecting even more complex" (e-mail communication, April 6, 2021).

Donor grant programs to incentivize rural and peri-urban electrification need to be reformed so that utilities have an incentive to cooperate with rather than eliminate well-functioning isolated or interconnected mini grids.

Compensation rules for non-interconnected mini grids in India

India has taken a very different approach from Africa's. As previously noted, Indian mini grids do not require government approval to operate, and there are no mandated compensation rules specified by state electricity regulators for takeover of mini grids in India. It is not required that the state or national regulator approve the tariffs that private mini grid operators charge their customers. The combination of these two legal exemptions, along with the absence of official sublicensing status for mini grids, means that Indian mini grids are essentially deregulated. However, it also means that, unlike Discos in Sub-Saharan Africa, Indian Discos have no legal authority to take over a mini grid's assets. Instead, a Disco's takeover of a mini grid's assets must be by mutual commercial agreement between the two parties.[26]

It was predicted that mini grids would not develop in India in the absence of a legally mandated compensation mechanism to reimburse mini grids for their capital costs when the main grid arrives in a village already being served by a mini grid (Comello and others 2015). Nevertheless, Smart Power India, a subsidiary of the Rockefeller Foundation, reported that, as of late 2022, more than 600 non-interconnected privately owned mini grids were operating in rural towns and villages in three Indian states. Many of these privately owned mini grids invested in villages already served by a local Disco—a seemingly riskier investment than investing in a mini grid in an isolated village. The likely explanation is that, in contrast to Discos in Sub-Saharan Africa, Discos in India do not have a unilateral legal right to take over the investments of private mini grids. However, the risk remains that Discos will improve the reliability and quality of service and take customers away from mini grids because of their lower (usually politically suppressed) tariffs.

Compensation rules for interconnected mini grids in Nigeria during the subconcession period

Nigeria is the first Sub-Saharan African country to specify compensation rules for interconnected mini grids. The rules apply to mini grids operating under a subconcession and interconnected to the local Disco from day 1 of the mini grid's operation. The mini grid is allowed to claim compensation from the Disco if the latter is in breach of its tripartite agreement with the mini grid developer and the community. The breaches included in the agreement template are expiration of a Disco's license, its inability to pay its loans, and evidence of untrue representations by the Disco (NERC 2016, annex 11).

An interconnected mini grid's economic viability depends on a Disco keeping its promise to sell electricity to the mini grid during evening hours (in the case of a firm supply commitment). An important question is whether a Disco's failure to supply this electricity constitutes a breach of contract. If a breach of contract does exist, the mini grid would seem to be entitled to the same compensation as for other breaches—namely, the depreciated value of remaining assets plus the previous 12 months of revenues earned by the mini grid.

Compensation rules for interconnected mini grids in Nigeria at the end of the concession period

Nigeria's tripartite agreements for interconnected mini grids typically provide for concession periods of 15–20 years. At the end of that period, the community must decide whether it wants the mini grid operator to continue to serve it or it wants the local Disco to return as the retail supplier. If a community wants the Disco to return (referred to in the regulations as "reintegration"), the Disco presumably has a legal obligation to provide retail service under the terms of its general license. This legal obligation may conflict with the Disco's financial incentives. A Disco will be reluctant to take over a mini grid's distribution assets if it can make more money by acting as a bulk supplier to the mini grid and collecting DUOS charges than as a retail supplier to end-use customers.

Consider the case of the Wuse market in Nigeria. In 2020, Abuja Electricity Distribution Company (AEDC), the local Disco, decided to transform itself from an electricity retailer to a wholesale supplier. By making this switch, AEDC projected that its revenues from Wuse market customers would increase by about 70 percent with only a small increase in costs. The move also meant that AEDC would collect revenues from a single customer, the mini grid owner and operator, rather than from more than 2,000 separate retail customers. AEDC would have a strong financial incentive to continue as a wholesale supplier, even if the tripartite agreement gives it the right to return as the market's retail supplier.

The economics of reintegration will vary from case to case. Wuse is a special case of a mini grid in an urban marketplace. The decision may be less clear-cut for an interconnected mini grid like the Toto mini grid, which proposes to serve a rural township.

At the end of the concession period, the key question a Disco will need to answer is whether it can make more money selling at wholesale and leasing out distribution assets to the mini grid than by taking over the mini grid's facilities and once again selling at retail.

REGULATION BY CONTRACT: TRIPARTITE AGREEMENTS IN THREE COUNTRIES

Tripartite agreements are used for mini grids operated by private developers in Haiti, Myanmar, and Nigeria.[27] The agreements share both similarities and differences (refer to table 3.2).

What types of mini grids are covered by tripartite agreements—and who are the signatories?

In Nigeria, tripartite agreements are used only for interconnected and non-interconnected mini grids in communities already served by a privately owned Disco. The signatories are the community, the mini grid developer, and the privately owned Disco whose service area includes the undergrid community that the mini grid developer proposes to serve. To facilitate the use of tripartite agreements, NERC appended a general template for tripartite agreements to its 2016 mini grid regulations (NERC 2016, annex 11)[28] and has stated that the

TABLE 3.2 Tripartite agreements in Haiti, Myanmar, and Nigeria

ITEM	HAITI	MYANMAR	NIGERIA
TYPE OF MINI GRID COVERED	All, including interconnected mini grids	All, including interconnected mini grids	Interconnected and non-interconnected undergrid mini grids
SIGNATORIES	• Municipal government • Mini grid developer • MTPTC	• Village electricity committee • Mini grid developer • Department of Rural Development	• Community committee • Mini grid developer • Local distribution company
REGULATOR	ANARSE (located within the MTPTC)	None; the Department of Rural Development plays a *de facto* regulatory role	NERC, the national electricity regulator
VEHICLE FOR GRANTS	Included in the concession agreement, which contains the tripartite agreement as an annex	Included in the tripartite agreement	Separate agreement with the REA

Source: Original table compiled for this publication.
Note: ANARSE = National Authority for Regulation of the Energy Sector; MTPTC = Ministry of Public Works, Transport and Communication; NERC = Nigerian Electricity Regulatory Commission; REA = Rural Electrification Agency.

template is for general guidance and that signatories may adapt it to the unique circumstances of individual projects.

Haiti and Myanmar use tripartite agreements for all mini grids. Developers in the two countries have proposed only electrically and geographically isolated mini grids. The government-owned national utilities in both countries are not signatories to the agreements, which therefore do not include provisions for compensation for the mini grid developer if the main grid arrives. The signatories are a community entity known as the Village Electricity Committee (Myanmar) or a municipal government (Haiti), the mini grid developer, and the ministry that provides capital grants to the mini grid developer.

In Nigeria, the regulator is NERC, which must review and approve all proposed agreements to ensure that they are consistent with NERC's regulations. NERC's approval of a tripartite agreement does not make NERC a signatory to the agreement, however.

In Haiti, the tripartite agreement is an annex to a concession agreement between the Ministry of Public Works, Transport, and Communications and the mini grid developer. Haiti's current mini grid regulations exist only in the model concession agreement and its annexes, which include the tripartite agreement, which is signed by the developer, the community's municipal government, and the ministry. Under Haitian law, a legally binding contract can be between only two parties. The tripartite agreement is therefore not formally considered a contract but is instead characterized as a three-party agreement.

Several Haitian lawyers have provided assurances that this agreement would stand up in court as a legally binding agreement. One would expect that the regulator would be legally bound by the terms of the concession agreement and its tripartite agreement annex, because the ministry signs the overall concession agreement and the regulator is part of the ministry.

Myanmar has no national electricity regulator. The Department of Rural Development within the Ministry of Cooperatives and Rural Development performs some regulatory role for mini grids. Mini grid developers know that they will not receive capital cost grants from the department unless they agree to the retail tariff ceilings and minimum service standards it specifies. The department is thus both the government's grant-giving entity and the de facto regulator.

Are there vehicles for grants? In Haiti and Myanmar, the grant agreement between the ministry and mini grid developer is embedded in the concession agreement (Haiti) or in the tripartite agreement (Myanmar). In Nigeria, the tripartite agreement and grant agreement are two legally separate documents. The grant-giving government agency (the REA) operates separately from the regulator of mini grid tariffs and service quality (NERC). The two entities receive separate applications from mini grid project developers. NERC receives applications for permits and tariff approvals. REA receives applications for grants.

Possible benefits of a tripartite agreement include the following:

- It tailors regulation to the circumstances of an individual community.
- It has explicit community buy-in, which creates a stronger commitment than if the community is simply an observer of a tariff order and permit or license approved by the national regulator in the distant capital.
- The commitment may be even stronger if a grant-giving ministry is a signatory to a tripartite agreement that includes a detailed retail tariff–setting system.
- It can be backed by some type of regulatory risk insurance (as discussed in appendix H) if a ministry is a signatory and the program's financing needs are large enough to attract commercial financing.

Whether these potential benefits materialize remains to be seen.

WILL THE GOVERNMENT HONOR ITS MINI GRID REGULATORY COMMITMENTS?

A regulatory system may look good on paper, but will it actually be implemented as written? The fear of mini grid developers and mini grid financiers is that regulatory rules and approvals will be just pretty words published in the government gazette but ignored or distorted in practice.

The fear of mini grid developers and mini grid financiers is that regulatory rules and approvals will be just pretty words published in the government gazette but ignored or distorted in practice.

In some countries, the political reality is that presidents, ministers, and members of parliament do not feel bound to honor the rules the regulator has issued. Ministers often do not accept the idea that regulators should be allowed to make decisions independently of the rest of the government, even if the law that established the regulator gives it independent authority to make decisions.

Retail tariff–setting decisions are often most vulnerable to being overturned just before national elections, as they were in Tanzania in 2020 (refer to box 3.3). Appendix H describes several insurance products that have been used to guarantee that a formal regulatory system will be implemented as written and also identifies the requirements for an insurance system that could bolster a formal regulatory system for privately owned and operated mini grids.

In the absence of a concession, would some type of insurance or guarantee mechanism be advantageous for groups of small private mini grid projects that sell to hundreds of households and commercial buyers? Such a mechanism would not be easy to devise, because mini grids led by private developers do not receive large concessions or subconcessions from either the federal government or a state government. They come into existence through licenses or permits, which are "approvals" rather than "commercial contracts," in which the government is a signatory to a contract.

In Nigeria, as we have noted, a non-interconnected mini grid must simply obtain the local Disco's no-objection agreement or an affirmation that the proposed project is not within the Disco's 5-year expansion plan, which is a prerequisite to issuance of a permit from the regulator. Even less government or Disco involvement exists in India. The more than 600 functioning mini grids in the states of Bihar, Jharkand, and Uttar Pradesh are simply unlicensed commercial entities that sell electricity at unregulated prices. They do not need the approval of the local Disco or the state regulator to enter the market.

A government official might reasonably ask why the government should enter into a concession when it is already seeing significant private investment without a concession. The answer is that a broad concession contract might lead to even greater private investment with lower overall financing costs. If this is the case and the concession contract can be backed by a guarantee or insurance policy, the government and the mini grid developer will need to know how much the insurance would cost and the likelihood that the benefit of lower financing costs will exceed the cost of the premiums (refer to appendix H).

NOTES

1. In Nigeria, for example, mini grids are required to obtain a certificate of imported equipment from the Standards Organization of Nigeria, an environmental and social impact assessment certificate from the Federal Ministry of Environment, a certificate approving major electrical materials from the Nigerian Electricity Management Services Agency, and consent of the Bureau of Public Enterprise for a Disco in which the federal government has a partial ownership interest through grants or a lease or a license with a value greater than US$1 million. This list is not comprehensive.
2. ESMAP (2022) offers a discussion of different mini grid delivery models; for a discussion of the approaches that governments can use to promote mini grids, refer to appendix A.
3. In a wide-ranging survey of power sector reform in developing countries, Foster and Rana (2020, 22) found that “although almost all countries grant regulators legal authority over tariff setting, this authority is respected in only about two-thirds of cases.”
4. The approvals by the electricity regulator accounted for 21 of the more than 52 weeks it took to obtain all approvals (Stephens 2021).
5. Chapter 5 describes a novel approach developed by Nigeria’s Rural Electrification Agency to speed the certification of milestones that trigger grant disbursements.
6. In June 2023, the president of Nigeria approved a new law that could lead to major changes in the regulatory structure of Nigeria’s electricity sector. The law allows state governments to create new state-level entities with potentially significant regulatory authority over electricity sector entities (including mini grids) operating in their state. It is too early to predict how this new law will affect mini grid development in Nigeria.
7. The government of Papua New Guinea is considering a different approach to the registration of mini grid service providers. Unlike Nigeria, registration is not based on the size of the installation. Instead, a mini grid service provider in Papua New Guinea will be allowed to register if it satisfies three criteria: it will operate at a low or extra-low voltage, it does not seek exclusivity to sell electrification services, and its proposed service area is outside a 10-kilometer band surrounding the national utility’s existing network. The regulator will review the proposed tariffs of mini grids that seek a license. It will not conduct an up-front approval of the tariffs of mini grids that register. However, if there is a future disagreement over tariffs of a registered mini grid, the regulator reserves the right to intervene on an ex post basis. The Papua New Guinea government is being advised by Trama TechnoAmbiental (https://tta.com.es), a consulting firm based in Spain.
8. Franchising arrangements are governed by the NERC Guidelines on Distribution Franchising in the Nigerian Electricity Supply Industry, published June 24, 2020 (NERC 2020).
9. Because the ministry is a high-level entity within the national government, the concession contracts it signs are usually viewed as a commitment by the national government. In contrast, although most regulators in the common law countries of Sub-Saharan Africa have the right to issue licenses or permits, they generally do not have the right to issue concessions or to enter into commercial agreements with the public and private entities they regulate. However, a ministry may enter into a concession (or a concession-like agreement)

that could contain the same regulatory terms and conditions found in the license issued by the national regulator plus other provisions. In countries that have no national electricity regulator, the ministry can function as the de facto regulator by issuing a concession.

10. The requirement of 8 hours of daily service is not a high hurdle for Husk Power or Tata Power Renewable Microgrid, India's two largest mini grid developers, which provide close to 24 hours of daily service.
11. This tariff-setting requirement is not triggered if the grant comes from India's central government or an international donor.
12. When an interconnected mini grid developer applies to NERC for approval of retail tariffs using the MYTO method, it must also submit 12 other documents: (1) an exclusivity agreement with the community, (2) a tripartite agreement with the community and local Disco, (3) a certified copy of incorporation, (4) the developer's memorandum and articles of association, (5) a certified copy of the certificate of occupancy or lease agreement for the site, (6) a certified copy of the building permit, (7) a map of the interconnected network, (8) a list of deficiencies in the distribution grid (signed by the developer and the Disco), (9) a map of the new distribution network infrastructure, (10) a map of the plot for the power-generation assets, (11) a diagram of fixed infrastructure for generation assets, and (12) boundary values of the distribution grid (Detail Commercial Solicitors 2020).
13. At a 2021 workshop on mini grid tariff regulation convened by the African Forum of Utility Regulators (AFUR), a mini grid developer observed that the Energy and Petroleum Regulatory Authority (the Kenyan electricity regulator) "tends to not approve tariffs that the model predicts" (Jha 2021).
14. AFUR is developing a new multiyear cost-of-service tariff-setting model (AESG 2021). The AFUR and NERC models appear to differ in at least three ways. First, the AFUR model does not have any provision for a performance-related profit margin. Second, the AFUR model gives the regulator the option to choose a depreciation method (straight line versus annuity), whereas the NERC model requires an annuity approach to depreciation. Third, the AFUR model is based on a "used and useful" approach, which creates a disincentive to oversize generation and distribution capacity in anticipation of future demand growth. "Used and useful" is a regulatory principle that requires that capital assets be physically used and useful to current ratepayers before the latter can be asked to pay the costs associated with the former.
15. A similar situation was faced by the US Federal Power Commission (FPC) in 1954, when the US Supreme Court ordered it to regulate the tariffs of several thousand natural gas producers on their bulk sales to natural gas pipelines. Initially, the FPC attempted to regulate the prices of the sales contract of every individual natural gas producer. Eventually, it gave up "because there were too many producers, too many contracts, and too many cost elements to determine prices on each sale" (MacAvoy 2000, 12). As an alternative, the FPC moved to area-wide price ceilings for 24 separate natural gas–producing basins in the United States. This effort also proved administratively unwieldy. In 1978, the US Congress passed a law that completely deregulated the prices charged by natural gas producers.
16. AMDA used a variant of this approach in its first annual benchmarking report of its members' mini grid projects in Sub-Saharan Africa, which covered 288 mini grids in 12 African countries. The effort compared average earned revenue per kWh sold rather than the approved tariff per kWh (AMDA, Economic Consulting Associates, and Odyssey Energy Solutions 2020). In Kenya, mini grid tariffs approved by the national electricity regulator are publicized on a project-by-project basis in the official government gazette.
17. The National Energy Regulator of South Africa reportedly performs benchmarking of the tariffs of the more than 180 municipal electricity distributors. The South African experience might provide insights on the feasibility of conducting a similar benchmarking exercise for mini grids.
18. One consultant in Nigeria estimated that, as of July 2021, non-interconnected mini grids were asking for and receiving approval of retail tariffs of N140–N180 (US$0.338–US$0.435). If the tariff were set at the cost recovery level computed using MYTO, it would justify a tariff of at least N200 (US$0.484).
19. This approach would also reduce the soft costs incurred by developers. A study by the Global Facility on Mini Grids of the costs of isolated mini grids found that "mini grids built as part of a portfolio saved on average $81,000 on soft costs compared with mini grids built as one-off projects." Soft costs comprise project development, general administration, planning, engineering, partnership, public relations, permits, approvals, licenses,

community engagement, and transportation (ESMAP 2022, 66). The savings in soft costs should also lead to lower mini grid tariffs over time.

20. It is not known whether the minimum required subsidies bid will be higher or lower than the US$600 subsidy (called performance-based grants) for developer-initiated projects.
21. Husk Power is operating six mini grid projects in the Nasawara state of Nigeria. It applied for separate permits for each of the projects rather than a single umbrella permit. Under the Interconnected Mini-grid Acceleration Scheme, or IMAS (described in appendixes B and C), some developers have created clusters consisting of three to four mini grids located near each other.
22. In Sierra Leone, mini grid developers pay a much lower DUOS charge. Mini grid developers using the government's distribution system pay a one-time fee of US$35 per connection rather than a fee based on the kWh sold during a specified period. Presumably, the government decided to subsidize private mini grid operators by charging a lower rental fee.
23. For an excellent conceptual analysis of the issues involved in setting compensation rules for a Disco's takeover of mini grid distribution assets, refer to Mathur (2020).
24. In general, compensation is not available if the mini grid chooses to simply register rather than to seek a basic license or permit. Typically, registration means that the mini grid operator is notifying the regulator of the project's existence without seeking the regulator's approval. In Nigeria, registration is allowed for mini grids with an installed capacity of 100 kW or less, though these smaller projects have the option of applying for a permit even though they are not required to do so. Mambwe and others (2022) provide a detailed survey of compensation rules that apply to Disco takeovers of mini grids in Sub-Saharan Africa.
25. If the takeover occurs during the initial period, developers can receive compensation for development costs (for example, in acquiring permits or meeting with government officials and financiers during the initial period). Developers do not receive compensation for development costs after the initial period and before the end of the subconcession period (for example, 15–20 years).
26. This topic was broached earlier without exploring its implications for compensation payments if a Disco takes over a mini grid's assets. The repetition is to remind the reader that the Nigerian and Indian legal frameworks for mini grids are very different and affect compensation outcomes.
27. Tripartite agreements for mini grids do not exist in India, primarily because electrically isolated mini grids in rural areas are exempt from both central and state regulation. If a household wishes to become a customer of a mini grid, it must sign a standard customer service agreement, the terms of which are dictated by the mini grid owner.
28. NERC has developed a separate template (NERC 2016, annex 12) for a community that is not currently served by the Disco in whose territory the community is located. This bilateral agreement is signed by the community and the developers of mini grids greater than 100 kW of installed generating capacity. Although the Disco is not a signatory to the agreement, it must (1) confirm that the mini grid's activities will not interfere with its expansion plans in that community or (2) provide written consent if the mini grid will be located in an area the Disco intends to serve within the next 5 years (NERC 2016, Section 7).

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4 Ensuring Win-Win-Win Outcomes

BENEFITS FOR RETAIL CUSTOMERS

Interconnected mini grids cannot be ordered into existence by policy makers or regulators. They will emerge only if they can be designed and operated to create outcomes that benefit mini grid customers, distribution companies (Discos), and mini grid developers.

Mini grids exist to provide electrical services that are better or less expensive than the end users already have. Doing so may appear difficult when the mini grids charge tariffs two to four times higher than those of the local Disco.

Mini grids are able to sign up customers because they offer better service. A survey of 10,000 rural households and 2,000 rural enterprises in four Indian states revealed that about 80 percent of household customers were satisfied with the service provided by their mini grid (Smart Power India and SAIS 2019). In contrast, only 60 percent of Disco customers said they were satisfied with the service it provided.

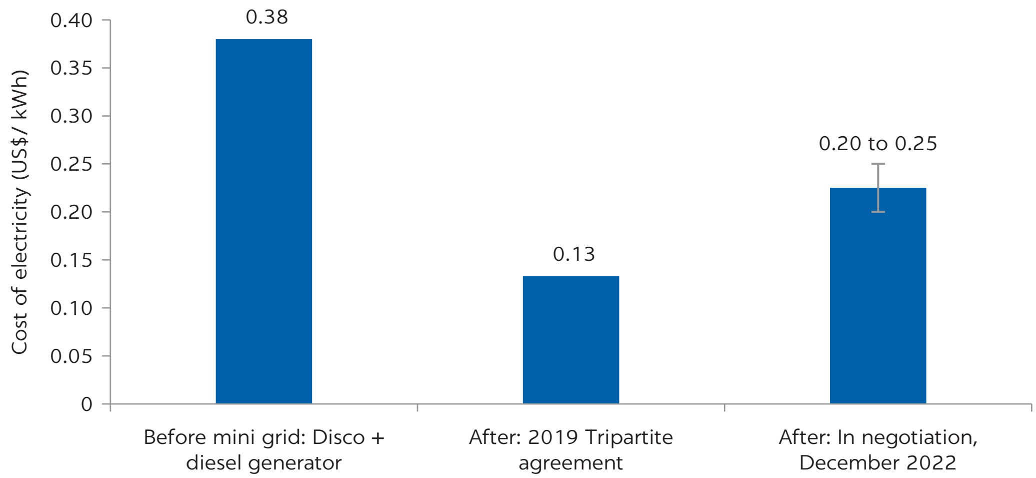
Price

Electricity purchased from the mini grid can replace both electricity obtained from the Disco and energy obtained from other sources, such as batteries, candles, kerosene lanterns, and electricity produced by diesel- or gasoline-powered generators. Mini grids often provide electricity for less than these customers pay for power from all of these other sources.

Consider this example. Before the arrival of the mini grid in Nigeria, the typical shop or stall owner in the Wuse market received electricity from two sources: the on-site electricity produced by small petroleum- or diesel-powered generators owned and operated by individual owners and the grid electricity supplied by the Abuja Electricity Distribution Company (AEDC). In 2019, the average blended cost of these two sources was US$0.38 per kilowatt-hour (kWh) (refer to figure 4.1). Once the mini grid takes over grid supply, the price per kWh for grid electricity will rise from US$0.077/kWh to US$0.133/kWh. However, because owners will no longer need to use expensive, self-generated electricity, they will pay about 65 percent less for electricity, and the supply will be more reliable.

FIGURE 4.1

Estimated cost of electricity to Wuse market customers before and after the mini grid, Abuja, Nigeria



Source: Original figure created for this publication based on data from PowerGen Renewable.
Note: Disco = distribution company; kWh = kilowatt-hour.

Reliability

For households, the most important dimension of good service is the reliability of supply, especially during prime evening hours. Kennedy, Mahajan, and Urpelainen (2020) estimate that unconnected customers would be willing to pay 13–48 percent more for electricity (roughly US$0.70–US$2.80 a month) for more reliable service. For a household with a few light-emitting diode (LED) lights, a cell phone, a fan, and a radio, this finding is consistent with a tariff of US$0.30/kWh.

Economists use the phrase "value of unserved energy" to quantify the losses that accompany outages. That value is the amount of money customers would be willing to pay to avoid an interruption. Data on the value of unserved energy in Nigeria are scarce, but a study conducted 20 years ago based on a nationwide survey of manufacturing firms estimated that the marginal cost of unserved energy in Nigeria was about 3.7 times the going rate for electricity (Adenikinju 2003). The study found that the lack of reliable electricity shapes decisions by Nigerian manufacturing firms on where to locate, what type of business to engage in, what factors to use in production, and whether or not to generate their own electricity. Power outages cause destruction of raw materials, lost output, restart costs, and damage to equipment. The survey of Nigerian manufacturers indicated that more than 60 percent of the respondents lost 10–50 percent of their potential output to power failures (refer to table 4.1), even while working longer hours. Two-thirds of respondents claimed that they made their employees work overtime to make up for the production lost during hours of power failure (Adenikinju 2003).

The survey of Nigerian manufacturers indicated that more than 60 percent of the respondents lost 10–50 percent of their potential output to power failures even while working longer hours.

Other benefits

Better service includes more accurate metering and billing and quicker responses to complaints. In India, Husk Power has committed to restoring service within

TABLE 4.1 Share of output loss caused by power failure in Nigeria in 1998

SHARE OF OUTPUT	PERCENTAGE OF RESPONDENTS
Less than 10 percent	19.6
10–30 percent	32.0
30–50 percent	30.1
More than 50 percent	18.3

Source: Adenikinju 2003.

4 hours for households and within 2 hours for commercial customers. It has also committed to compensate customers if the company determines that it was responsible for a loss of service. (How often it has done so has not been confirmed.)

BENEFITS FOR DISCOS

In Nigeria, most Disco executives were initially opposed to accepting interconnected mini grids in their licensed service area. In off-the-record conversations, it was not uncommon to hear comments like the following:

> Why would I want to help someone who is going to be a competitor and who could take away parts of my business? And it is not fair competition. These mini grid developers get performance grants from the Rural Electrification Agency for every new customer they connect. And they are allowed to charge tariffs that recover their costs. But I don't get the same grant and regulatory treatment. The regulator has not kept his promise to allow me to charge cost-recovering tariffs, so it shouldn't be surprising that I don't have the money to invest in new equipment to improve service. And I'm also at a competitive disadvantage because I'm prohibited from owning generation. This means that I'm totally reliant on unreliable upstream sources supplied by third parties. When this upstream supply of electricity is not available or is unreliable, I am the one who gets blamed even though it is not my fault. In contrast, the government lets these mini grid developers build and operate their own generation close to load. They don't have to depend on unreliable upstream electricity supplies.

In recent years, a different view began to emerge among some Disco managers in Nigeria. It goes something like this:

> Look, this is a no-brainer. I'm happy to off-load serving this community to someone else because I am currently losing a lot of money in serving these customers. Why? First, I am not allowed to charge tariffs that recover my true costs of serving the community. Second, it is very hard to collect money from these customers because they are understandably unhappy with the service that I am able to provide. If a mini grid developer is willing to take over serving this community and also pay me a rental fee for using my distribution system, I say great. And if I can also sell bulk electricity to the mini grid developer without the collection headaches that I currently face in this town, why wouldn't I want to do it? Look, there is no long-term risk to me. If the developer succeeds in making the area profitable, the tripartite agreement with the developer and the community specifies that I can always take back the territory and the improved distribution system at the end of the concession period.

How can one make sense of these two very different views of the world? If we are going to make an informed judgment about these two outlooks, we need to take a close look at the numbers. Specifically, what are the following:

- The existing profits and losses for Discos serving rural communities?
- The likely revenues from leasing out the distribution grid in one or more communities?
- The potential revenues from bulk sales to interconnected mini grids?

Revenues from existing electricity sales to rural customers

In its 2018 *Under the Grid* report, the Rocky Mountain Institute (RMI) estimates that a typical Nigerian Disco with 4,500 rural customers lost an average of US$0.21 per kWh distributed, equating to about US$22,000 per year (RMI 2018b). Because the average mini grid in the Interconnected Mini-grid Acceleration Scheme (IMAS) is about half that size, with 2,280 customers (refer to appendix J), we conservatively adjust losses on a pro rata basis to US$11,000 per year.[1] The losses are caused by tariffs allowed by the regulator that do not cover costs, as well as technical losses and poor collections.

RMI estimates that allowed tariffs covered only about 35 percent of a typical Disco's costs. It also finds that the typical Disco collected only 30 percent of the billed amount from unmetered customers and 50 percent from metered customers. "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," RMI concludes (RMI 2018a, 14).

In the Toto community, the Disco has been unable to provide service for the past several years because of weakness in the distribution infrastructure and issues such as customer delinquency (personal communication with Chukwuma Obi Collins, December 24, 2022). Its poles and wires were depreciating in the field while generating no revenues.

A Disco in Nigeria should have a strong incentive to hand off any parts of its service franchise on which it is losing money to a mini grid operator who is willing to take on the Disco's responsibility to serve these customers. This transfer need not be permanent: if the mini grid operator makes the service area commercially viable, the tripartite agreement gives the Disco the legal right to take it back at the end of the agreement period, typically 15–20 years.

Revenues from the Distribution Use of System charge

In addition to offloading loss-making areas, both interconnected and non-interconnected mini grids in underserved areas provide Discos with the potential to earn new revenues. In two of the Nigeria case studies (Mokoloki and Wuse), the local Discos stand to collect payments by allowing the mini grids to use the Discos' existing distribution system. Wuse will pay about US$0.03 per kWh sold; the fixed monthly fee paid by Mokoloki is confidential. The Distribution Use of System (DUOS) fee will be reported to the Nigerian Electricity Regulatory Commission (NERC) as part of any mini grid's retail tariff filing.

The DUOS charge will be negotiated; therefore, it is difficult to predict what it will be for any given mini grid project. The US$0.03/kWh value for the Wuse mini grid is probably on the high side, because the AEDC distribution grid serving the urban Wuse market was in relatively good condition. This situation will probably not be true for existing mini grids in rural and peri-urban communities.

Estimates for the first six proposed interconnected mini grids supported by the IMAS project are that 60–80 percent of the existing distribution system is usable. Mini grid operators are likely to argue that the DUOS charges should be lower, because these operators will have to replace and rehabilitate a larger share of the infrastructure than was true for the Wuse project.

Early evidence from the IMAS projects is that the DUOS charge for mini grids serving rural and peri-urban towns and villages is more likely to be in the range of US$0.006–US$0.013 per kWh sold at the retail level—about US$3,300–US$7,100 a year for the average IMAS project. Notwithstanding the differences in the quality of their distribution networks, Discos try to maintain the same rate for all developers with projects of similar size, irrespective of location in their franchise, because the DUOS amount is determined by multiyear tariff calculations that apply to the entire franchise. However, to support some of these projects, Discos may set a lower DUOS tariff (for example, half the usual amount) for the first 5 years to allow the project to gain viability and customer acceptance, after which full recovery is made in later years of the project (personal communication with Chukwuma Obi Collins, December 24, 2022).

In contrast, Indian mini grid companies have opted to build totally new distribution systems rather than try to use the distribution grid of the local Disco, because (1) existing Disco systems are often old and in poor condition and (2) interconnecting to the local Disco would subject the mini grids to extensive state and central government regulatory rules. If they do not interconnect to the local Disco, they remain essentially deregulated.

Revenues from bulk electricity sales to the mini grid

A second source of revenues for Discos connected to mini grids is from bulk sales of electricity to the mini grids. A mini grid will have an incentive to interconnect to the Disco if it can provide electricity at a lower price than the mini grid's cost of generating the same electricity from its own supply sources.

The six IMAS-supported mini grids projected that they would be able to buy electricity from their local Discos at prices of 30–60 Nigerian naira, or N (US$0.073–US$0.145). These figures compare with an estimated current cost of approximately US$0.50/kWh for electricity generated from an on-site diesel generator and similar costs for electricity cycled through batteries. Five of the first six interconnected mini grids plan to receive electricity from the local Discos for 4 hours per evening. It is estimated that the Discos will earn an average of about US$12,000 in profits per year from each of the five interconnected mini grids targeted for rural and peri-urban towns.

Analysis by RMI finds that, for a single illustrative community, the Disco can avoid 60 percent of current financial losses by agreeing to let a mini grid serve the same community (refer to figure 4.2). Losses can be mitigated by eliminating the costs of bulk power purchases, distribution, and variable operating expenses. On average, the Disco will save at least N5,300 (US$15) per connection per year through an undergrid mini grid. Additional savings through a usage fee further improve the finances.

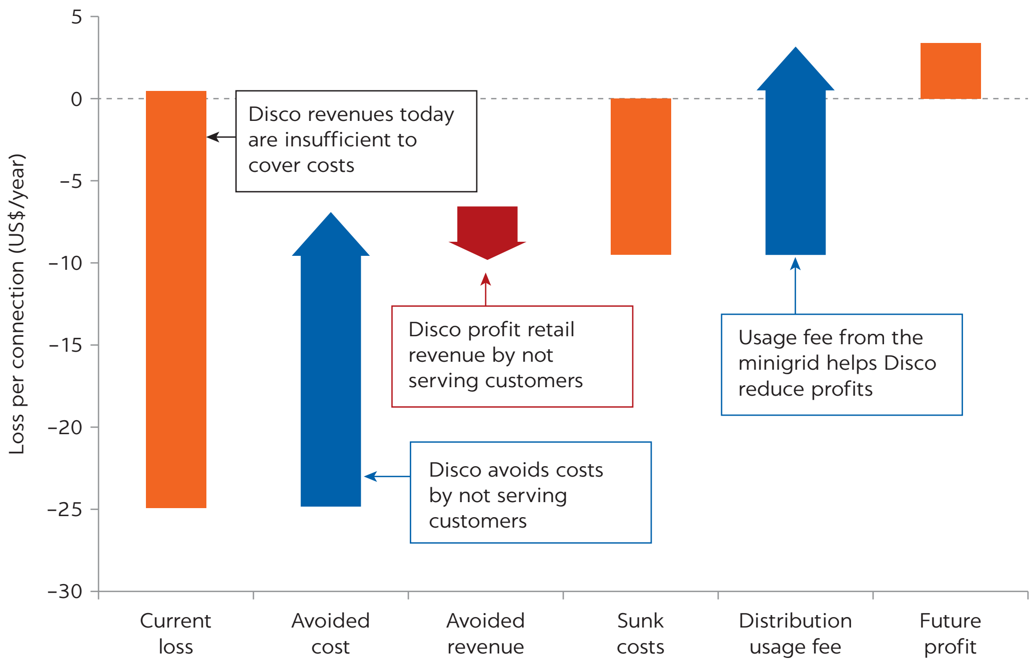
Analysis by RMI finds that, for a single illustrative community, the Disco can avoid 60 percent of current financial losses by agreeing to let a mini grid serve the same community.

A Disco will need to answer three questions before deciding whether it should sell bulk electricity to an undergrid mini grid:

1. **Should the sale be firm or nonfirm?** In the case of the Toto and the Wuse market mini grids, AEDC (the local Disco) will sell firm electricity during prespecified hours to both mini grids. If it fails to satisfy its commitments, it

FIGURE 4.2

Effect on Disco profitability of contracting with an undergrid mini grid



Source: © Rocky Mountain Institute (RMI). Used with permission by RMI; further permission required for reuse.
Note: Disco = distribution company.

will be liable for penalties. Many Nigerian Discos will not be willing to make firm commitments because of uncertainty about the reliability of their upstream electricity supply and the need for upstream repairs to the feeder lines leading into the mini grid.

2. **What price will the Disco be allowed to charge for the sale of bulk electricity?** In Nigeria, recent bulk supply prices are tied to the retail prices the Disco is allowed to charge its retail customers under the NERC-approved service-based tariff system established for all 11 Discos at the beginning of 2021. Some mini grid developers have argued that the retail price is too high because the Disco will be supplying bulk electricity to the mini grid at the substation level, which means that it will not incur the distribution costs embedded in the NERC-approved retail tariff. In their view, the Disco should be allowed to charge the lower NERC-approved price for sales at the substation level.
3. **What investments are needed to make the sale possible?** The Disco may have to make capital investments to rehabilitate the feeder line that connects to the mini grid. The capital investment may be significant if the line is in poor condition. From the Disco's perspective, it may not make financial sense to make these investments, if doing so leads to only small additional power sales to the mini grid. Another consideration is that the feeder line may also be serving non–mini grid customers located upstream. Once the feeder line is repaired, the Disco may incur additional losses if these customers are largely unmetered or continue to be served at retail tariffs that do not recover the Disco's costs. The additional sales revenues earned on bulk electricity sales to the now-connected mini grid may be partially or totally offset by increased losses incurred in serving other upstream customers on the same improved feeder at non-cost-recovering tariffs.

BENEFITS FOR MINI GRIDS

Connecting to a Disco benefits mini grids by providing them with electricity at lower cost and allowing them to sell excess electricity back to the Disco.

Lower electricity costs

If an interconnected mini grid can purchase electricity from the local Disco or some other main grid–connected supplier, it can potentially lower both its operating expenses (OPEX) and capital expenses (CAPEX). The reduction in OPEX occurs if the price the mini grid pays for electricity purchased from the Disco is lower than the cost of self-supplying the same amount of electricity from an on-site diesel generator or batteries and inverters on the mini grid's distribution system. The reduction in CAPEX occurs if the purchase of electricity from the Disco allows the mini grid to reduce its overall investment in equipment (batteries, solar panels, and diesel generators).

If an interconnected mini grid can purchase electricity from the local Disco or some other main grid–connected supplier, it can potentially lower both its operating expenses (OPEX) and capital expenses (CAPEX).

Types of Disco supply commitments

The reduction in the cost of mini grid electricity will be greatest if the mini grid is confident that the Disco can provide a firm electricity supply—a supply that is guaranteed for certain hours every day. As an alternative to a firm commitment, the local Disco may offer to supply bulk electricity to the interconnected mini grid on a nonfirm or "best efforts" basis. In this case, the risk of nonsupply will be borne by the mini grid. In general, a mini grid purchasing electricity on a nonfirm basis might expect that electricity will be unavailable for purchase from the Disco during evening peak load hours, because the latter will be prioritizing supplying its limited electricity at that time for its own retail customers.

If the Disco's electricity supply is offered only on a nonfirm basis, the mini grid will need to maintain sufficient on-site backup supply within its service area, in the form of greater installed capacity for the mini grid's on-site batteries and photovoltaic (PV) array or a larger diesel generator. The first six interconnected mini grids in Nigeria's IMAS program have decided to install on-site generation and storage capacity sufficient to provide firm electricity supply to their retail customers whenever the local Disco is unable to provide its promised electricity. The preferred backup supply for interconnected mini grid developers is a larger diesel generation system. For the same backup capability, the capital costs of a diesel generator are lower than the capital costs of battery storage, and a well-maintained diesel generator can supply electricity as long as diesel fuel is available, whereas a battery's ability to meet load is typically limited to several hours. However, the operating costs of diesel generators are high compared with those of solar PV and battery storage, so generators are generally dispatched as a last resort.

Fortunately, even an intermittent Disco supply can reduce the cost of electricity by taking advantage of grid electricity when it is both available and needed and using it to power loads directly or to charge batteries. Table 4.2 estimates the per-kWh fuel cost of electricity generation at diesel fuel prices. Many centralized grid systems that are stretched thin during daytime and evening hours have greater availability of electricity in the middle of the night, when commercial and industrial (C&I) activity is reduced and most people are asleep. These savings are generally limited to OPEX, because the "as available" nature of the

TABLE 4.2 Fuel-only cost of electricity generation from diesel (US dollars)

PER LITER OF DIESEL FUEL	PER KWH
0.50	0.16
0.75	0.24
1.00	0.32
1.25	0.40
1.50	0.48
1.75	0.56
2.00	0.64

Source: Generator Source, Approximate Diesel Fuel Consumption Chart (https://www.generatorsource.com/Diesel_Fuel_Consumption.aspx).
Note: Cost calculations do not include capital expenses and nonfuel operating expenses. These calculations assume a typical efficiency for a well-maintained 60-kilowatt diesel generator operating at 75 percent capacity that produces about 3.1 kWh per liter of diesel fuel. Fuel consumption depends on a number of factors, including generator maintenance, quality, capacity, and utilization level (percentage of maximum capacity). kWh = kilowatt-hour.

electricity supply means that the mini grid will need to be able to meet its full load when electricity is not available for sale from the Disco.

Required mini grid reliability in Nigeria

In Nigeria, it is critical that the interconnected mini grids in the IMAS program have a backup supply that is under their complete control, because the model tripartite agreement issued by the Nigerian regulator requires that mini grids provide electricity to their retail customers with 95 percent availability. If a mini grid fails to meet this standard, it can be penalized. As an interconnected mini grid developer might put it:

> What I am selling to my customers is a much higher reliability during the key evening hours than the local Disco is capable of providing. Supplying electricity during these evening hours is critical to the success of my business model. If I can't provide a reliable supply of electricity during these evening hours, then I don't have a viable business model.

Cost savings from purchases of "as available" (nonfirm) electricity

To explore cost savings from interconnecting a mini grid to intermittent electricity from a Disco, we use data on the proposed IMAS mini grids, with modeling support from the Integration Consulting Group. To maintain the confidentiality of individual projects, a single hypothetical project was created using average component unit costs from the first six mini grids being supported under the IMAS program. This hypothetical project was optimized for a load profile equal to the average of these first six IMAS mini grids. Appendix J provides details on the modeling assumptions about the cost of different mini grid components, the load curve, and the solar resource. We used the mini grid modeling software Hybrid Optimization of Multiple Electric Renewables (HOMER) Pro to simulate hourly dispatch throughout a full year, considering seasonal variations in solar resources and variations in the load curve.[2] Values for the levelized cost of electricity (LCOE) are determined by the CAPEX needed to build a mini grid and the OPEX needed to keep it running. LCOE combines these costs into a single cost per kWh to deliver electricity to mini grid customers over the lifetime of the mini grid. This value is equivalent to the minimum average tariff a mini grid developer would need to charge if the project were to be commercially viable.

To model the "as available" basis on which the Disco sells electricity to the IMAS projects, we assume that electricity is available from it for a continuous duration (we have modeled 2, 4, 6, and 8 hours) with random start times but with electricity that is never available during the Disco's peak hours (5–9 pm).

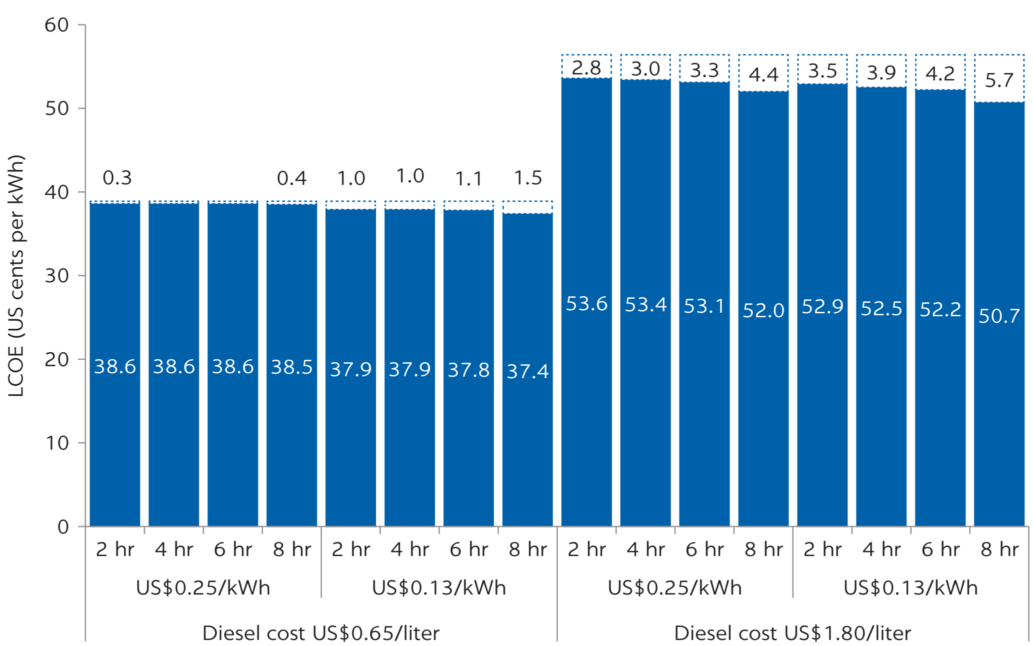
For the first six proposed interconnected mini grids in the IMAS program, the local Discos originally offered to sell electricity for US$0.11/kWh–US$0.17/kWh. These prices are based on the wholesale prices that Discos pay the Transmission Company of Nigeria. To investigate the impact of base case and possible future high wholesale tariffs, we modeled wholesale electricity supply tariffs of both US$0.13/kWh and US$0.25/kWh.

The benefits of purchasing electricity from a Disco depend not only on the price of the purchased electricity but also on the cost of diesel fuel, because purchases from the Disco allow the mini grid to consume less fuel for backup generation. In early and mid-2021, the cost of diesel in Nigeria was approximately US$0.65/liter. By November 2022, the price had shot up to US$1.80/liter,[3] partly as a result of the war in Ukraine.

In the modeling results, the average LCOE from an unsubsidized IMAS mini grid that never receives electricity from the Disco's grid is US$0.389/kWh and US$0.564/kWh for diesel prices of US$0.65/liter and US$1.80/liter, respectively. Figure 4.3 shows the results of modeling the savings that would accrue by connecting the aggregate/synthesized IMAS mini grid to a nonfirm electricity supply from the Disco, as compared with not connecting, under the following conditions: diesel prices of US$0.65/liter and US$1.80/liter; electricity available

FIGURE 4.3

Levelized cost of electricity in a hypothetical IMAS mini grid purchasing nonfirm electricity from a Disco



Source: Original figure created for this publication based on data from the Interconnected Mini-grid Acceleration Scheme (IMAS).

Note: Blue bars show the levelized cost of electricity (LCOE). The white segments above the blue bars indicate the savings realized by connecting to the Disco. Each column represents a different scenario, distinguished by the number of hours of Disco supply (2, 4, 6, or 8), the wholesale price of electricity purchased from the Disco (US$0.25/kWh or US$0.13/kWh), and the cost of diesel fuel (US$0.65/liter or US$1.80/liter). Disco = distribution company; kWh = kilowatt-hour.

from the Disco at random hours for 2, 4, 6, or 8 hours per day; or purchased electricity priced at US$0.25/kWh and US$0.13/kWh.

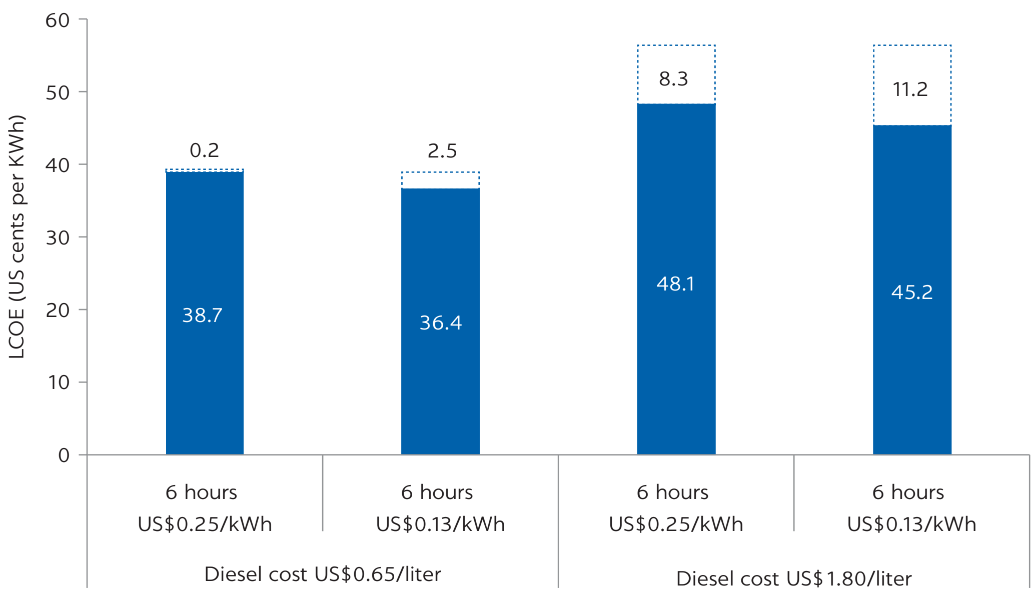
The availability of even intermittent electricity from the Disco saves the mini grid money. The savings depend on the tariff the wholesale Disco charges as well as on the price of diesel used to power the on-site diesel generator. If the cost of diesel is low (US$0.65/liter) and the cost of electricity from the Disco high (US$0.25/kWh), the savings from purchasing electricity over self-generation from diesel are minimal (just US$0.003/kWh if electricity is available for purchase 8 hours per day). This saving is equivalent to a reduction of about 0.8 percent of the LCOE versus not connecting to the Disco. In a middle case, when electricity tariffs and diesel prices are both either low or high, the savings range from US$0.01/kWh (when 2 hours of electricity are available) to US$0.015/kWh (when 8 hours of electricity are available)—savings of 2.6–3.9 percent. With a high diesel price (US$1.80/liter) and low cost of electricity from the Disco (US$0.13/kWh), savings are nearly US$0.06/kWh (when 8 hours of electricity are available each day)—just over 10 percent as compared with not being connected.

Cost savings from purchases of firm electricity

Savings can be higher when electricity from the Disco is firm. Figure 4.4 indicates the cost savings when the same hypothetical IMAS mini grid is connected to a firm supply of electricity for 6 hours every night (6 pm–12 midnight—the hours during which AEDC has committed to supply electricity to PowerGen's Toto mini grid system described in chapter 2).

FIGURE 4.4

Cost savings in a hypothetical IMAS mini grid connecting to 6 hours of firm supply from a Disco



Source: Original figure created for this publication based on data from the Interconnected Mini-grid Acceleration Scheme (IMAS).

Note: Blue bars indicate the levelized cost of electricity (LCOE). The white segments above the blue bars indicate the savings compared with not connecting to a Disco. Each column represents a scenario defined by the wholesale price of electricity purchased from the Disco (US$0.25/kWh or US$0.13/kWh) and the cost of diesel fuel (US$0.65/liter or US$1.80/liter). The duration of firm supply is assumed to be from 6 pm to 12 midnight, the time and duration that the Abuja Electricity Distribution Company provides to PowerGen's Toto grid-connected mini grid. Disco = distribution company; kWh = kilowatt-hour.

If these supply conditions were applied to the average interconnected mini grid in the IMAS program, they would produce an LCOE savings of about 6.4 percent, assuming a fuel price of US$0.65/liter and a wholesale electricity price of US$0.13/kWh. These are roughly the same prices that PowerGen was expecting when the PowerGen case study was written. Our estimates are a bit lower than PowerGen's expected 10 percent reduction in the LCOE but are consistent when one considers that, in practice, Toto will also benefit from purchasing nonfirm electricity in the "available hours" in addition to the firm electricity supply in "priority hours."

Savings from firm supply of electricity vary substantially under different diesel fuel prices and wholesale electricity costs. On the low side are virtually no savings (US$0.002 [0.5 percent]) in the case of expensive wholesale electricity (US$0.25/kWh) and inexpensive diesel fuel (US$0.65/liter). At US$0.13/kWh and US$1.80/liter, the savings rise to US$0.112/kWh—nearly 20 percent as compared with a non-interconnected mini grid. These figures illustrate the risk-reducing value of power purchases as a hedge against diesel price volatility.

The impact of firm versus nonfirm power is significant. Comparing figures 4.3 (nonfirm) and 4.4 (firm), savings are roughly twice as much for firm electricity (6 hours from 6 pm to 12 midnight every night) than they are for nonfirm electricity (available 6 hours a day but at random hours).

Comparing figures 4.3 (nonfirm) and 4.4 (firm), savings are roughly twice as much for firm electricity (6 hours from 6 pm to 12 midnight every night) than they are for nonfirm electricity (available 6 hours a day but at random hours).

Whether power purchases from a Disco reduce CAPEX depends largely on the degree to which power purchases from it are firm. In the face of contracts offering only nonfirm power, the IMAS-supported mini grid developers and their advisors decided to take a conservative engineering approach, sizing the mini grid based on the assumption that power would never be available from the Disco. It is difficult to optimize a mini grid system in the face of high uncertainties about how often and at what times of day electricity will be available. Any approach would need to weigh the upside and downside impacts of the availability and nonavailability of Disco electricity on the expected LCOE. The downside of guessing wrong (burning more diesel fuel or failing to meet power availability commitments) might well be more costly than the upside of guessing right (forgoing some investment in solar panels or batteries).

Both PowerGen (Toto case study 2) and Green Village Electricity (Wuse market case study 3) have purchase agreements with AEDC that provide for the sale of firm electricity; both reduced their investments in batteries and solar panels as a result. Their confidence in paring down CAPEX investment reflects their confidence that the power supply commitments will be met.

One would not expect a Disco to offer a firm supply commitment unless it had a high level of certainty that the feeder line leading into the community and the upstream electricity supplies were adequate to support a firm sales commitment to the mini grid. If electricity supply from a Disco is firm, the contract should include provisions that require the Disco to pay a penalty to the mini grid whenever it fails to honor its commitment. Without such a penalty, the firm supply commitment is not credible.

The tripartite agreements between AEDC and the Toto and Wuse interconnected mini grids contain penalty provisions if AEDC fails to supply the expected electricity.[4] The tripartite agreement between the Wuse market and AEDC includes a provision that would compensate Wuse with N12 (US$0.029) for every kilowatt-hour AEDC fails to supply.

If a Disco fails to supply electricity as promised, a mini grid operator will still need to decide whether it makes commercial sense to try to enforce the contractual commitment in a court of law. In the Wuse market case, the compensation mechanism would operate through a reduction in the monthly DUOS rental charge that Wuse would otherwise pay to AEDC.

The compensation provisions for the Toto interconnected mini grid project are different. Because Toto will not be paying a DUOS charge for most of the agreement period,[5] it is to be compensated for any failure of AEDC to meet its firm supply commitment based on the extra cost of generating electricity from on-site generation. The compensation payment will be made through a reduction in the energy charges Toto would otherwise pay for the remaining electricity AEDC supplies, up to a specified monthly amount. This provision is useful for making the mini grid developer financially whole if the contractual violations are small or infrequent. If the violations become major or frequent, other contractual mechanisms kick in that allow the developer to renegotiate its tariff and modify its installation. Although this arrangement is not ideal, it is better than trying to force the Disco to pay for differences during the duration of the original agreement.

Revenues from mini grid electricity sales to the Disco

In principle, mini grids could earn revenues by selling electricity back to the Disco. They might choose to do so if they have excess electricity or can deliver electricity profitably to the Disco at times when it is willing to pay high prices.

With a few non-PV exceptions,[6] we have found no examples of mini grid sales to Discos. Most interconnected mini grids will not have significant surplus capacity unless the PV arrays are oversized (which the IMAS program discourages). Because Discos can buy power from Nigeria's market operator at approximately N9–N10 (US$0.022–US$0.024)/kWh, they are unlikely to be willing to purchase electricity from mini grids at higher prices. In Nigeria, net metering arrangements have yet to be approved by the regulator because of concerns about the effect of bidirectional power flow on the already fragile grid network. Dispatch operators have not yet been trained, and the system is not yet configured, to handle the potential complexity of net metering from a technical standpoint (personal communication with Chukwuma Obi Collins, December 24, 2022). On the mini grid operators' side, there is the risk that they would not be paid for the electricity they sell to the Disco. Tanzania's Small Power Producer program was crippled by delays of 6 months or more in payments to mini grids and independent small power producers by the national utility, the Tanzania Electric Supply Company Limited.

Taking these factors into consideration, grid-connected mini grids have decided that the risks and costs associated with overcoming the regulatory and technical challenges necessary to accommodate sales to the Disco are not worth the likely revenues. As solar PV costs fall, bidirectional power flows are more likely, particularly during daytime, if the mini grid has excess solar production and batteries are full, especially if transmission constraints limit a Disco's ability to purchase electricity from a national market operator. Storage costs will likely need to decrease significantly before Discos are willing to pay tariffs that cover the costs of storing electricity in batteries.

SUMMARY OF POTENTIAL BENEFITS

Table 4.3 summarizes the very preliminary numbers coming out of Nigeria (in particular) and India. The figures have wide bands of uncertainty.

TABLE 4.3 Initial assessment of the benefits of interconnected mini grids to customers, Discos, and mini grid developers in undergrid areas

GROUP BENEFITING	NATURE OF BENEFIT	QUANTITATIVE ESTIMATE OF BENEFIT	COMMENTS
Customers	Increase in daily service hours	Toto: Availability rose from 0 to 24 hours (promised). Mokoloki: Rose from 4–5 hours to 19 hours (5 am–midnight).	Mokoloki shut down service from midnight to 5 am to keep monthly diesel expenditure within the original budget estimate of US$10,000 (specified in the tariff filing with NERC).
	Lower cost than backup diesel generators and sporadic supply of electricity from the main grid	Wuse: The blended cost per kWh before the mini grid was US$0.38/kWh. As of August 2023, a tariff of US$0.20/kWh–US$0.25/kWh was under negotiation.	The average Wuse market shop or stall owner spent N9,561 (US$23.15) on electricity produced from its own generator and N3,031 (US$7.34) on electricity produced by the AEDC, for a total monthly expenditure of N12,600 (US$30.51). The average blended cost of these two supply sources was US$0.38/kWh. Once the mini grid becomes fully operational, the tripartite agreement specifies that owners will pay N55 (US$0.133)/kWh to GVE (based on 2020 data). As of August 2023, GVE and the Wuse Market Traders Association were negotiating a higher retail price to accommodate GVE's cost increases since the original tripartite agreement was signed.
Discos	Relief from having to serve loss-making communities	In Toto, the Disco was unable to provide service and therefore earned no revenue on its distribution assets before mini grid arrival.	RMI (2018a) estimates that a typical Nigerian Disco serving a rural area lost an average of US$0.21 per kWh distributed. These losses average US$22,000 a year for a typical Disco serving 4,500 customers (about US$11,000) for the average IMAS mini grid.
	Revenues from leasing poles and wires (DUOS charges)	Wuse: US$0.029/kWh. Most of the first five IMAS projects with signed tripartite agreements will pay a DUOS fee of N3–N6 (US$0.007–US$0.015)/kWh with provision for escalation up to N15 (US$0.036) in year 10. The N3–N6 fee works out to US$3,300–US$7,200 per year.	Mokoloki reached an agreement with IBEDC to pay an annual lump sum. In other interconnected mini grids the Disco will typically seek a DUOS fee tied to the kWh distributed by the mini grid.
	Revenues from bulk kWh sales	Wuse: US$0.11/kWh–US$0.17/kWh (firm supply commitment). Toto: Not known. First five IMAS projects: N30–N60 (US$0.073–US$0.145)/kWh.	Discos sell electricity to mini grids at service-based tariffs approved by NERC. As the term implies, the arrangement ties tariffs to the service level (for example, number of hours of electricity per day) achieved by the Disco on individual feeders. Some mini grids argue that a more appropriate price should be the bulk supply price at the feeder substation rather than the price for retail service for end-use customers served by the same substation, which includes distribution and retailing costs that the Disco is no longer incurring.
Mini grid developers	Lower levelized cost of electricity	Nonfirm supply: Savings of 0.8–10.0 percent of the levelized cost per kWh. Firm supply: Savings of 1–20 percent.	Savings are highest with low prices for Disco-supplied electricity and high diesel prices; savings are lowest with high prices for Disco-supplied electricity and low diesel prices. Nonfirm power sales from the Disco to the mini grid are likely to be the norm in early interconnected mini grid projects in Nigeria. Once Discos gain more experience selling to mini grids, they may be willing to offer firm commitments on some feeders.

Source: Original table compiled for this publication.
Note: AEDC = Abuja Electricity Distribution Company; Disco = distribution company; DUOS = Distribution Use of System; GVE = Green Village Electricity; IBEDC = Ibadan Electricity Distribution Company; IMAS = Interconnected Mini-grid Acceleration Scheme; kWh = kilowatt hour; N = Nigerian naira; NERC = Nigerian Electricity Regulatory Commission.

NOTES

1. If the mini grid is losing money on the sale of every kilowatt-hour, cutting the number of customers in half translates to roughly half as many kilowatt-hours sold and thus roughly half the monetary losses. Economies of scale will make things worse for smaller projects, all things being equal—thus our use of the term *conservatively*.
2. For more on HOMER Pro, visit https://www.homerenergy.com/.
3. GlobalPetrolPrices.com, Nigeria Diesel Prices, https://www.globalpetrolprices.com/Nigeria/diesel_prices/ accessed November 22, 2022.
4. The template contract in Obi and others (2022) includes provisions very similar to the Toto and Wuse contract provisions.
5. In the Toto project, PowerGen's investment in the distribution grid is netted against the DUOS charge, bringing net DUOS payments to zero.
6. Tenenbaum, Greacen, and Vaghela (2018) discuss micro-hydropower mini grids that sell excess electricity to the national grid in Indonesia and Sri Lanka.

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5 Technical Design of Mini Grids That Interconnect with the Grid

"Smarter microgrids can communicate on an ongoing basis with their parent grid, forming a beautiful friendship."

—David Roberts (Roberts and Chang 2018)

DESIGN CONSIDERATIONS FOR INTERCONNECTION

The new generation of solar mini grids can interconnect with the national grid to reduce customer costs and provide high levels of reliability and resilience against natural disasters. This chapter comprises two sections. The first discusses the technical requirements for grid interconnectivity. The second focuses on reliability and resilience.

The grid-interactive commercial options discussed in chapter 4—buying or selling electricity from a distribution company (Disco)—require special equipment (refer to table 5.1). Interconnection can be simple (the mini grid's distribution wires may be the only items that connect to the main grid) or more complex (the mini grid is connected to the larger grid in ways that allow electricity to flow in both directions and also allow the mini grid to quickly disconnect and continue to serve mini grid customers with its storage and generation assets).

The connection of mini grids to the national grid raises six questions:

1. Will the mini grid's distribution network—but not its generation and storage systems—connect to utility power?
2. Will the national grid ever be used to charge the mini grid's batteries?
3. Will electricity ever flow from the mini grid to the national grid?
4. How will islanding and reconnection be accomplished?
5. Can the mini grid's inverter(s) provide ancillary services, such as voltage support, to the national grid?
6. Is the distribution network of the mini grid built to safely interface with grid power?

TABLE 5.1 Additional equipment needed for a mini grid to be able to buy from and sell electricity to the Disco

EQUIPMENT	A: MINI GRID PURCHASES ELECTRICITY DURING SOME HOURS FROM THE DISCO FOR RESALE TO ITS CUSTOMERS	B: MINI GRID SELLS ELECTRICITY TO THE DISCO	A + B: ELECTRICITY FLOWS BOTH WAYS
Step-down/step-up transformer, distribution switchgear (including isolators, changeover switch), and energy meter(s) that record energy flows in both directions[a]	✓	✓	✓
Inverter that can synchronize and inject power into the Disco's grid (able to operate either in grid-forming or grid-following mode)		✓	✓
Mini grid distribution grid built to Disco grid standards[b] (compliant with specifications for poles, cross-bars, insulators, and conductors; refer to box 5.2)	✓		✓

Source: Original table compiled for this publication.
Note: Additional here means beyond what would be needed to operate in a self-supply (islanded) mode. When in islanded mode, the only supply to customers is from the mini grid's generation and storage assets (photovoltaic, generator, batteries). Disco = distribution company.
a. Metering arrangements must resolve whether meters are on the low-voltage or high-voltage side of the transformer. Implicit in this choice is who pays for idling losses for the transformer. If the meter is on the high-voltage side, the mini grid pays for the idling losses; if it is on the low-voltage side, the Disco or other supplier pays.
b. "Built to Disco grid standards" is an easy proxy for safety. A separate but safe standard for low-power distribution networks is possible. This issue merits further discussion.

Will the mini grid's distribution network—but not its generation and storage systems—connect to utility power?

If the answer to this question is yes, the electrical engineering is fairly simple. If power flows in one direction from the national utility to the mini grid's distribution network, and no mini grid generation assets are synchronized with the utility power, all that is generally needed is a transformer to step down the utility's medium voltage (for example, 33 kilovolts or 11 kilovolts) to the low-voltage (typically 230-volt single-phase or 400-volt three-phase); distribution switchgear; and an energy meter to measure the amount of electricity the mini grid purchases from the Disco.[1] In this modality, the mini grid can maintain its generation capability as a backup, provided the switching is built such that the distribution network cannot be simultaneously connected during normal operation to both utility power and power generated by the mini grid.

The simplest way to accomplish this is with a double-throw switch (sometimes called a changeover switch), which allows the distribution wires to be energized by either source but never by both. Many inverters have this functionality built in, allowing alternating current (AC) grid power, when available, to pass through, with the unit automatically disconnecting the grid lines and switching over to inverter power when grid voltage is not present or does not meet quality thresholds. The equipment installed in the Wuse market mini grid is of this type.

If the mini grid's generation network is connected to the national grid, the requirements are more complicated, as explored later in this chapter.

Will the national grid ever be used to charge the mini grid's batteries?

If the national grid is also used to charge the mini grid's batteries, the arrangement is only somewhat more complicated. The conceptually simplest (but also somewhat rare) variant of this case is one in which a dedicated battery charger is connected to the national grid's low-voltage lines. When these lines are energized, electricity flows through the charger, charging the batteries if they are able to accept more charge. Flow of current is inherently one-way, because battery chargers convert electricity from AC to direct current (DC) but cannot convert from DC to AC.

A more common variant is that the mini grid's battery inverter has a battery-charging functionality.[2] This variant is less expensive than having a separate inverter and battery charger because the inverter's transformer and associated components inside the inverter are often engineered to provide double duty: (1) inverting (that is, going from DC to AC) electricity stored in the mini grid's batteries to energize the mini grid's distribution line when the national grid is not energized; and (2) switching over to allow the national grid to serve both the load and to charge batteries when the national grid is energized and operating within an acceptable frequency and voltage range. Here as well, the flow of current is one way (from the national grid to the mini grid). Mini grids may provide an analogous service to smaller generation systems located downstream, usually in residential areas of the mini grid's service area (refer to box 5.1).

Will electricity ever flow from the mini grid to the national grid?

It is often mutually beneficial for electricity to flow from the mini grid to the national grid. This situation could arise when the mini grid has an excess of electricity or when the Disco has a high need for electricity and is therefore willing to pay prices for electricity that cover the mini grid's marginal cost of generation or storage.

BOX 5.1

DC solar mesh grid connecting downstream from an AC mini grid

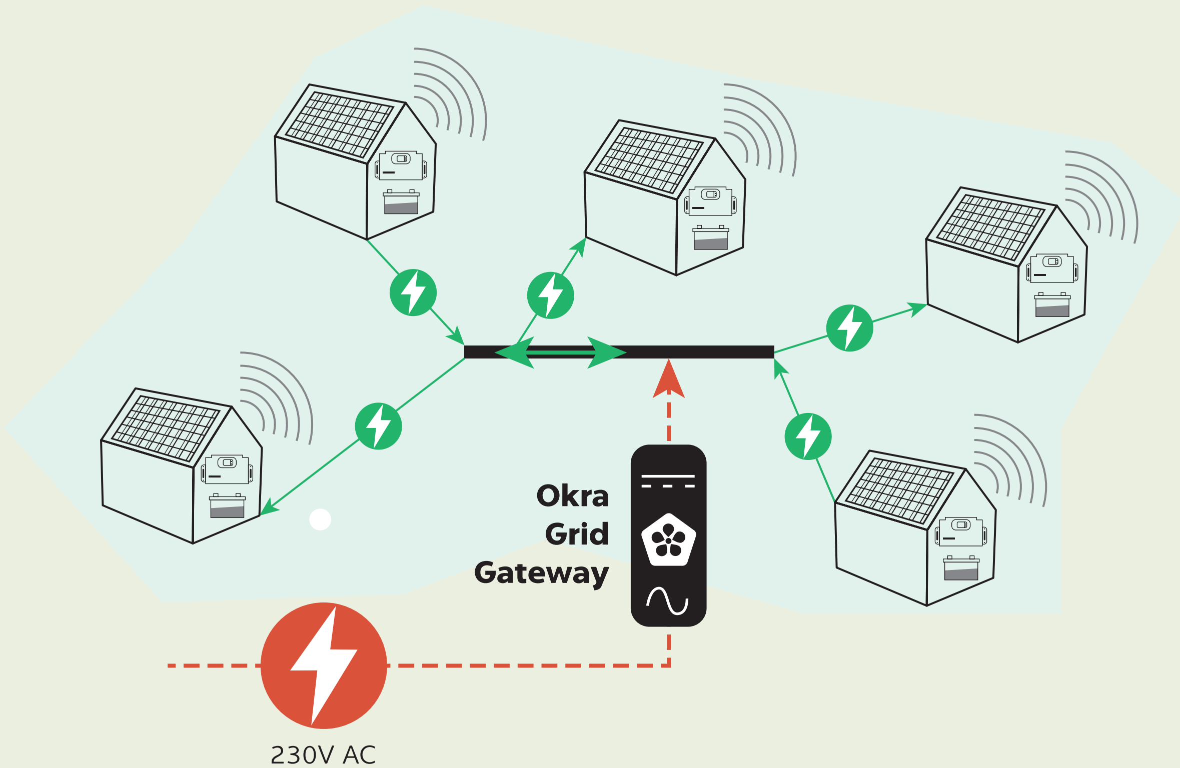
This book focuses on upstream interconnection (an interconnection between a mini grid and a distribution company [Disco] or other main grid entity). However, it is also possible to build downstream interconnections between an alternating current (AC) mini grid and a direct current (DC) solar mesh grid or "skinny grid," which take the form of clusters of solar home systems made up of solar panels affixed to customers' premises and connected in a mesh network. Okra Solar (www.okrasolar.com) builds distributed solar mesh grids that provide low-cost connections for residential areas that have too low a density to be viable to connect to a typical centralized mini grid. Okra controllers at each customer's premises manage the sharing of surplus electricity over 50-volt DC distribution wires. If the customer wants to use AC appliances, Okra will supply an inverter at the customer's premises to convert electricity from the DC mesh network to AC.

In addition, the Okra mesh system can be built with a gateway connection to nearby upstream AC grids. The Okra Grid Gateway is an AC-to-DC converter that can provide additional electricity from a nearby main grid (or an AC mini grid) to power loads and charge batteries in homes of customers on an Okra mesh grid (refer to figure B5.1.1). This arrangement could be attractive on the periphery of a main grid or AC mini grid, reaching clusters of low-consumption customers for whom extending the AC distribution network might be cost-prohibitive.

(*Box continues on next page*)

Box 5.1 DC solar mesh grid connecting downstream from an AC mini grid (*continued*)

FIGURE B5.1.1
Okra Gateway converting AC for use in a DC mesh grid



Source: © Okra Solar. Used with permission; further permission required for reuse.
Note: AC = alternating current; DC = direct current; V = volt.

To enable the flow of electricity from the mini grid to the national grid, the mini grid's inverter will need to have the capacity to synchronize with the national grid, matching the frequency and phase so that it can inject current into the larger grid's waveform. Synchronizing rotating generation (such as diesel generators or small hydropower) with an external power supply requires special equipment: sensors that monitor the frequency and phase of both the generator and the main grid, and trigger a relay to close a switch when they are matched. Many battery inverters accomplish this task internally, without the need for external relays. Inverters that have this capability are referred to as "grid-interactive," "dual mode," or "multimode." They are made Fronius, Huawei, Outback, Schneider, and System, Mess and Anlagentechnik (SMA), among other companies.

How will islanding and reconnection be accomplished?

We define *islanding* as the operation of an electricity-generation facility in electrical isolation from the larger grid. When a mini grid islands from the main grid, it becomes a separate power system that is able to serve its customers without transferring power into or out of its electrical island. According to this definition, all mini grids covered in the case studies can island—either sometimes (Mokoloki, Toto, and Wuse) or always (Husk and Tata).

Some utility engineers may raise concerns at the mention of islanding because they operate with the narrower definition of *islanding* as a situation in which a generator that had been synchronized with the main grid switches to temporarily generate electricity independently from the main grid. This concern is raised with regard to grid-connected generators failing to disconnect or shut down when the grid has a blackout or other major disturbance. Many distributed generators, such as solar farms, that are connected to the main grid are engineered to avoid islanding. Utilities are often concerned that in the (very) unlikely event that these anti-islanding protections fail, the distributed generator may continue to inadvertently energize a portion of the main grid's lines. Although it is common practice for utility workers to ground lines they are working on to ensure that they are not energized, utilities sometimes raise concerns that line workers might assume the lines are not energized during a failure of the central grid, opening up the risk of electrocution if the lines are indeed energized.

With appropriate safety and control mechanisms, intentional islanding can provide reliable service to mini grid customers in locations where the utility grid is unreliable. In all of the case studies presented in chapter 2, the mini grid's generator is wired to the network (with an automatic or manual transfer switch) in such a way that neither the generator nor the solar panels and inverters can energize the main grid lines in the event of a power outage. The inverter injects current into the main grid lines only when the lines are energized and injects AC electricity only in synchronization with the utility's 50-hertz (Hz) electricity waveform.

If the system is designed to accommodate the flow of electricity in both directions, the requirements for safely transitioning to and from islanding mode become more complicated. Implementing intentional islanding in such a case requires that the system perform several steps reliably, in correct sequence, and with correct timing:

1. If the quality (frequency, voltage) of electricity from the national grid falls outside an acceptable window or is shut off completely, the inverter disconnects from the grid.

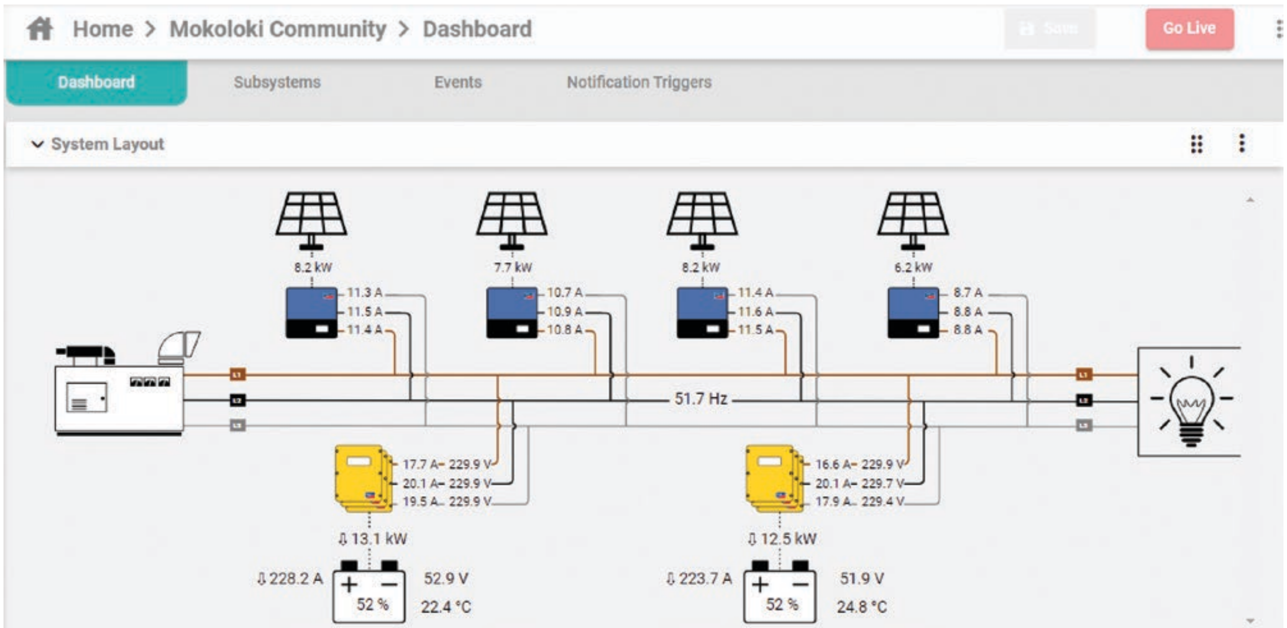
2. Upon disconnecting, the inverter must immediately switch from synchronized to autonomous mode, engaging controls to create its own 50 Hz waveform. The transition to stand-alone (islanded) mode in some inverters happens within 35 milliseconds, or less than two cycles (SMA n.d.), fast enough that the transition is generally not noticeable.

3. In island mode, the inverter continually monitors the condition of the national grid and reconnects once the grid electricity is stable again for several minutes. Before reconnection, the mini grid's generation must be synchronized with that of the main grid (IEEE 2011).

Fortunately, widely available grid-interactive inverters, including those used in the case studies in this book, can rapidly and safely automatically transition from grid-connected generating mode to an intentional island mode and back again. Switching from one mode to another depends on the conditions of the load and the availability of electricity from the national grid. Inverters used in the Mokoloki (refer to figure 5.1), Toto, and WUSE mini grids described in the

FIGURE 5.1

Screenshot of online Mokoloki mini grid dashboard



Source: © Mokoloki LTD. Used with permission; further permission required for reuse.
Note: This screenshot shows the configuration and status of generation, storage, and power conversion in the Mokoloki grid in Ogun state, Nigeria. Two banks of SMA Sunny Island battery inverters configured as three-phase clusters (yellow) convert electricity stored in the battery to AC on the distribution network, either in grid-forming mode (creating their own 50-Hz frequency), when the diesel generator is not operating, or in a grid-following mode, synchronizing with the diesel's 50 Hz frequency when the diesel is operational. PV inverters (blue and black) never operate in grid-forming mode. They always synchronize with the distribution network, injecting current into the waveform when AC power is present. In this image, the diesel generator is off, the PV panels are creating power in excess of the load, and the battery inverters are using this excess power to charge the batteries. If the mini grid had a connection to the national grid, the system would include a transfer switch that would allow a choice between the diesel generator and the national grid. A = ampere; AC = alternating current; Hz = hertz; kW = kilowatt; PV = photovoltaic; SMA = System, Mess and Anlagentechnik; V = volt.

case studies have the capability to transition from islanding to grid-connected and back; however, because regulatory arrangements and tariffs do not favor interconnecting and operating in a grid-connected mode, this capability has not yet been actualized.

The ability to island quickly and to seamlessly transition into and out of an islanded state enhances reliability for the mini grid customer. With batteries, solar generation, and diesel generators, the mini grid can operate in an islanded mode for hours and potentially much longer, limited only by the supplies of diesel fuel and sunshine.

Can the mini grid inverter(s) provide ancillary services, such as voltage support, to the national grid?

In addition to injecting raw power into the national grid, grid-interactive inverters in solar mini grids can provide ancillary services, such as voltage support. Regulation of voltage by a grid-connected distributed generator often depends on the preference of the utility's distribution engineers. Whereas frequency is the same value at any given moment across the utility's entire electric power system, voltage varies somewhat from node to node throughout the system, depending on the distribution of loads, generation, and the capacitor banks used for power-factor correction. In some locations, utilities may prefer that electricity injected by the mini grid be at a constant power factor (power-factor control mode), which helps ensure that the utility's efforts at regulating voltage (often through capacitor banks, load tap changers, and voltage regulators) are not complicated by the distributed generator or inverter simultaneously regulating voltage. In other cases, particularly in parts of the distribution system where utilities do not have good voltage regulation, the utility may ask the distributed generator to regulate voltage (voltage-control mode). Utilities often make this determination based on a power flow study, in which the system voltages, currents, and power flows are modeled under minimum and maximum load conditions with the addition of the proposed distributed generator.

Batteries and inverters already provide regional grid networks in the United States with a host of additional stacked services, including demand charge reduction (for the Disco's purchase of electricity from the transmission company or an upstream generation company), transmission congestion relief, resource adequacy, spinning and nonspinning reserve (reducing the need for the country's generation companies to have power plants ready to go in the event of a malfunction), and frequency regulation (EIA 2021). A 2015 report from the Rocky Mountain Institute, or RMI (Fitzgerald and others 2015) reviews studies that quantify the financial value of 13 services in the United States that customer-sited batteries could provide to customers and the grid (refer to table 5.2).

Mini grids, with and without batteries, could technically provide many of these same services. However, considering the high levelized cost of storage (refer to appendix G), developers would have to look carefully at whether the payment for these services warranted the expense of the wear and tear on batteries.

In many countries, the ability of mini grids to be compensated for contributing in these ways is more constrained by regulatory barriers than by technology. In the United States, the landmark Federal Energy Regulatory Commission Order 2222, approved in September 2020, set the stage for these transactions by requiring six regional transmission organizations to allow aggregated

TABLE 5.2 Services in the United States that customer-sited batteries could provide to customers and the grid

SERVICE	DETAILS
Independent system operator/regional transmission organization services	Energy arbitrage
	Frequency regulation
	Spinning/nonspinning reserves
	Voltage support
	Black start
Utility services	Resource adequacy
	Distribution deferral
	Transmission congestion relief
	Transmission deferral
Customer services	Time-of-use bill management
	Increased photovoltaic self-consumption
	Demand charge reduction
	Backup power

Source: Fitzgerald and others 2015.

distributed energy resources to participate in regional organized wholesale capacity, energy, and ancillary services markets alongside traditional power plants. Such regional markets for ancillary services do not exist in Sub-Saharan Africa, but it is conceivable that the emerging power pools in Africa (such as the Southern African Power Pool or the West African Power Pool) could provide the market structure for such trades. If they come into existence, they could provide an additional revenue source for interconnected mini grids beyond power sales to local mini grid customers and the connected Disco.

Is the distribution network of the mini grid built to safely interface with grid power?

If a mini grid is to connect as a small power distributor that purchases electricity at wholesale prices and sells it to customers at retail prices, it must be able to distribute the electricity safely. Most regulators in Sub-Saharan Africa have adopted regulations that require mini grids to build their distribution network to the same standards as the national grid (EEA 2020; EWURA 2019; RURA 2019). This is a reasonable approach if the national grid standard is appropriate for levels of consumption by customers in the service area. However, it is also reasonable to ask whether long-established distribution standards are still a good fit, especially for small customers whose electrical loads are limited to efficient lighting and electronics (refer to box 5.2).

BOX 5.2

Matching distribution standards with rural loads

In many places, mini grids that connect to the national grid are required to be built to national grid standards. Whether these standards are appropriate given loads in the service area is not clear. In many cases, poles, conductors, and associated hardware used to serve rural customers must meet standards designed for larger urban customers with higher consumption patterns (for example, using air conditioners and electric cooking appliances), even when rural customers have (and will have for the foreseeable future) loads that are much more modest.

Norms and standards for electricity networks are often based on concepts imported during colonial times, with little adaptation to local conditions. For example, poles and wires may be engineered to withstand snow and ice, which is not relevant in tropical climates (ESMAP 2006).

Regulators should look for opportunities to adopt, and builders to implement, appropriate lower-cost standards where feasible. Such measures may include allowing the use of single-phase in addition to three-phase distribution, allowing the use of a single-wire earth return distribution network where conditions permit, and innovations to save costs on poles, such as allowing insulators to be attached directly to the pole rather than to a crossbar. These innovations pertain primarily to the poles and wires that distribute electricity to customers and are generally separate from and will not interfere with the operation of the conductors that constitute the interconnection with a distribution company (Disco).

Questions about grid-connected mini grid distribution network standards may help prompt a broader review and revision of rural medium- and low-voltage standards, with the goal of lowering costs consistent with local loads and harnessing opportunities to use available materials if their use can lower life-cycle costs without sacrificing reliability or safety.

Further analysis of grid interconnection

The six questions addressed are by no means comprehensive. Beyond the scope of this analysis is the question of what type of interconnection is optimal—a small power distributor, with power flowing one way from the Disco to the mini grid's distribution network; a small power producer, with the mini grid selling electricity to the Disco; or a combination of the two. Sometimes the answer to this question is limited by what is permitted by the regulatory framework or by considerations of realpolitik involving the Disco. Where multiple options are available and the relative tariffs do not rule out options as being obviously economically unfeasible, a comprehensive analysis of costs and benefits of each approach may be needed.

The question also arises of which node (for example, electrical pole) within the mini grid's distribution network is optimal for establishing an interconnection point with the main grid and installing associated transformers to minimize losses and costs. Chikumbanje (2022) provides a theoretical framework for addressing these optimization problems.

DESIGN CONSIDERATIONS FOR RELIABILITY AND RESILIENCE

One of the attributes of solar hybrid mini grids that is most highly valued by their users is their high reliability and high resilience. Micro/mini grids are increasingly used to enhance the reliability and resilience of electricity supply. The ability of grid-connected mini grids to island and operate independently from the main grid allows them to offer critical facilities such as hospitals, data centers, and water treatment plants the ability to remain energized and operating after a disruption to the main grid. Loads powered by mini grids—whether grid-connected or isolated—generally receive much more reliable electricity than loads powered by national grids.

The ability of grid-connected mini grids to island and operate independently from the main grid allows them to offer critical facilities such as hospitals, data centers, and water treatment plants the ability to remain energized and operating after a disruption to the main grid.

Designing reliable mini grids

Reliability—defined as the "adequate, safe, and stable flow of electricity" (Ott 2018)—is generally measured using the duration (System Average Interruption Duration Index [SAIDI]) and frequency (System Average Interruption Frequency Index [SAIFI]) of power outages in a typical year. SAIDI measures outages in terms of outage hours per customer each year, and SAIFI measures how many interruptions occur per customer per year. Instead of SAIDI, the mini grid community sometimes uses the more intuitive measurement of uptime, defined as the percentage of time a mini grid is operational. In its 2022 benchmarking report, the Africa Minigrid Developers Association (AMDA) finds that most of its members' mini grids reported uptimes of over 99 percent (AMDA, Economic Consulting Associates, and Odyssey Energy Solutions 2022). Husk Power's Industry road map notes a substantially higher cost to build mini grids at 99 percent uptime than at the lower bar of 97 percent (Mattson, Sinha, and Brent 2022). Box 5.3 explains the distinction between uptime and SAIDI.

A 2022 study (Ferrall, Callaway, and Kammen 2022) compared SAIDI and SAIFI in 2,000 randomized rural Kenyan and Tanzanian households powered by mini grids against the same metrics for 59 sensors in urban Nairobi and 25 in

BOX 5.3

How do SAIDI and uptime differ?

System Average Interruption Duration Index (SAIDI) and uptime both pertain to reliability. SAIDI is more nuanced, whereas uptime is more intuitively understood.

SAIDI is defined as follows:

$$SAIDI = \frac{Sum\ of\ all\ customer\ interruption\ durations}{Total\ number\ of\ customers\ served}$$

Uptime is defined as follows:

$$Uptime = \frac{Total\ hours\ of\ availability\ in\ a\ year}{8{,}760\ hours}$$

with 8,760 hours being the number of hours in a year.

For larger utilities, outages often happen on individual feeders, resulting from, say, a tree falling on distribution lines. In the event of a local outage, only a fraction of customers is affected. Because of the way SAIDI is defined, outages that affect fewer customers have a smaller impact on it. A generation failure would affect everyone, contributing more to SAIDI.

Uptime lacks the nuance of accounting for the number of customers affected. It makes sense where power outages affect all customers. In a mini grid with a robust distribution system, all outages may be the result of inadequate sunlight, equipment out for repairs, or diesel backup not being available. Uptime presumes a single measuring location (for example, at the powerhouse); SAIDI requires data from the meters of each customer, or at least a way to log the availability of electricity at each feeder.

If all outages affect all customers, a conversion between SAIDI and uptime is

$$SAIDI = (1 - Uptime) \times 8{,}760$$

or, alternatively,

$$Uptime = 1 - \frac{SAIDI}{8{,}760}$$

For example, an uptime of 99 percent would translate to a SAIDI of (1 – 0.99) x 8,760 = 87.6 hours.

Dar Es Salaam. The authors find that rural mini grids had better reliability (lower SAIDI and SAIFI) measurements than urban household customers in both Dar Es Salaam and Nairobi. The average SAIDI for mini grids was 379 hours of outages per year across 10 rural mini grids in Kenya and Tanzania, compared with 419 hours per year for main grid–connected households in Kenya and 1,154 hours per year in Tanzania. Mini grids in Kenya and Tanzania had an average SAIFI of 65.7 disruptions per year per household; the main grid in Kenya had an average SAIFI of 81, and Tanzania averaged 300. Mini grid SAIDI and SAIFI figures were captured using Sparkmeters, which, in addition to serving as revenue meters for mini grids, allow operators to collect detailed performance data, including voltage readings at time-stamped intervals.

Uptime, SAIDI, and SAIFI are part of a broader set of power quality metrics that include not only metrics on how often and how long power is out but also measures of the quality of power when it is available. For readers interested in a more comprehensive evaluation and grading of mini grid power quality, the US National Renewable Energy Laboratory, in partnership with the Global Lighting and Energy Access Partnership and the US Agency for International Development's Power Africa, has developed a Mini Grid Quality Assurance Framework (QAF).[3] The QAF is a "truth in advertising" framework that provides a clear mechanism for validating power delivery and providing information on mini grid performance to customers, funders, and regulators. It outlines tiers of end-user service that mirror the Multi-Tier Framework defined by the World Bank (Bhatia and Angelou 2015) and links them to relevant technical parameters. Data generated through implementation of the QAF provide the basis for comparisons across projects and assessment of impacts.

The QAF defines three levels of service: basic, standard, and high. The high level of service is equivalent to modern utility-scale power systems. Factors that determine these levels of service for an AC mini grid include the following:

- Voltage imbalance
- Voltage transients
- Short-duration voltage variations
- Long-duration voltage variations
- Frequency variations
- Unplanned SAIFI and SAIDI
- Planned SAIFI and SAIDI (to be considered for power systems not designed to provide full-time power; planned SAIFI and SAIDI allow the mini grid not to count the time the mini grid was planned to be turned off).

Implementation partners can choose among these metrics to customize the QAF for parameters that are important to the country or region, balancing the cost of data collection against the usefulness of the indicator for the types of loads they are likely to encounter. For these variables, the QAF provides a common framework for accountability and performance reporting and a clear process for validating power delivery. The choice of data to collect reflects a balance of the cost of collecting the data (some electrical measurements require more costly data logger transducers[4] than others) and the value of the data (the data's relevance for delivering power at the reliability and power quality levels that are important for customers based on the loads that they are expected to use).

The QAF has been implemented in Nigeria,[5] in partnership with the country's Rural Electrification Agency and its national mini grid program; in Myanmar (supported by the German Corporation for International Cooperation [GIZ][6] before the military coup in February 2021); and in the Programme Haïtien d'Accès des communautés Rurales à l'Energie Solaire (Haitian Program for Access to Solar Energy in Rural communities; PHARES) energy access program. Other implementations have focused on supporting the development of regulatory frameworks, including the recently released mini grid regulation in Uganda implemented by the Energy Regulatory Agency, and a new mini grid system regulation under development in Haiti.

Papua New Guinea has included a framework similar to the QAF in its proposed small power producer regulations, which distinguish between "service quality" and "power quality."[7] The proposed regulations require that the agreed-on values for service quality and power quality be specified in a service contract between the mini grid provider and the community. The regulations are still at the proposal stage; therefore, it is not known whether the community and regulator will be able to monitor the mini grid's compliance with the values specified in the service contract.

Designing mini grids for resilience

Resilience is the ability to rebound from a major shock, such as a hurricane, major flooding, a large earthquake, human attacks, or a combination of unprecedented events (Ott 2018). Most of the mini grids being developed in the United States are designed to provide resilience for critical infrastructure facilities (Long 2020). With the extreme weather conditions produced by climate change, weather-related shocks will become more frequent, and what was once thought of as a resilience issue may increasingly be seen as a reliability issue.

If a hurricane or earthquake results in failure in some or all of the main grid…, the principal resilience solution for the interconnected mini grid is to island itself from the main grid…. [to] protect the mini grid's customers for the duration of the upstream problem.

With centralized generation and hundreds or thousands of miles of transmission and radial distribution networks that must constantly and instantaneously match supply with demand, main grids can be particularly vulnerable to significant shocks at crucial locations. If a hurricane or earthquake results in failure in some or all of the main grid (for example, an upstream problem on the transmission grid or lack of available generating supply), the principal resilience solution for the interconnected mini grid is to island itself from the main grid. Islanding does not solve the upstream problem, but it does protect the mini grid's customers for the duration of the upstream problem. In Puerto Rico, mini grids are being developed because of the fragility of the island's main grid in the face of hurricanes.

Although they are a valuable tool for increasing resilience, mini grids, like all power systems, are susceptible to major shocks. Hurricanes can rip solar panels loose from their racks (photo 5.1), flooding can destroy electronics, and falling trees can destroy distribution networks. Roads damaged by earthquakes can disrupt the supply of diesel fuel for backup generators.

Measures taken by mini grid installers and operators to increase the reliability of electricity supply will increase resilience. Building and maintaining robust generation and distribution networks, designing in redundancy in generation supply, and incorporating preparations that enable quick and efficient restoration in the event of an outage are all measures that increase reliability and enhance resilience.

With mini grids, there may be occasional trade-offs between reliability and resilience. For example, in the face of an approaching hurricane or cyclone,

PHOTO 5.1

A mini grid damaged by Hurricane Matthew in Les Anglais, Haiti

Photo credit: ©EarthSpark International. Used with permission; further permission required for reuse.

a mini grid operator may choose to remove all solar panels for safe storage to wait out the storm, reducing short-term reliability (at least as measured by SAIDI) in the hours just before the storm so as to facilitate recovery after the storm (resilience).

The Rocky Mountain Institute (RMI) publication *Solar under Storm* (Stone and Locke 2020) analyzes failure mechanisms for mini grids in small island states in the Caribbean and South Pacific. It finds that, although solar mini grids were more resilient to hurricanes and cyclones than diesel-based mini grids, thanks to their far lower reliance on diesel supply chains, their survival in the face of extreme winds varied from installation to installation. Engineering practices found in the solar photovoltaic (PV) installations most resilient to hurricanes include the following:

- Bolting PV modules to racks rather than using top-down clamps that hold down the frame of a module or T-clamps that hold two adjacent modules. T-clamps that hold adjacent modules are particularly problematic because, if one module is torn loose from high winds, the T-clamp releases tension on the adjacent module and modules can "unzip" from the rack.
- Using clamps (if clamps must be used) that hold a single module rather than two adjacent modules.
- Completely disassembling the array (again, if clamps are used) and storing the PV modules in a shipping container before a storm arrives.
- Ensuring that all bolts are tightened to required torque specifications.
- Ensuring that racks have lateral supports.
- Specifying high-load (up to 5,400 Pascals uplift) PV modules in hurricane-prone areas.

The RMI study estimates that incorporating measures that allow PV projects to withstand Category 5 hurricanes (wind speeds of 157 mph or higher) would increase engineering, procurement, and construction costs by only about 5 percent over projects built to the current industry standard (Category 3, up to 129 mph; or Category 4, up to 156 mph). These additional costs come in the form of labor for the extra time needed to fasten modules and install more connections, as well as additional hardware costs (Stone and Locke 2020). The EnDev publication and video series "PV Mini-Grid Installation Dos and Don'ts" discusses best practice installation techniques that enhance reliability and resilience (GIZ 2021).

NOTES

1. Two or more AC generation sources are synchronized when their voltage, frequency, and phase are in step, rising and falling together. An attempt to electrically connect generation sources that are not synchronized will generally result in severe damage to one or more generators.
2. An inverter converts DC electricity to AC. Mini grids with battery storage have one or more battery inverters that convert DC electricity stored in the batteries to AC on the mini grid's distribution network. When operating in electrical isolation from an external AC source, these battery inverters are "grid forming" (that is, they create the mini grid's AC frequency). They may also serve as battery chargers, converting AC electricity from an external source to DC to charge the batteries. The mini grid will also need PV inverters that convert DC electricity from the solar panels to AC on the mini grid's distribution network or PV charge controllers that charge the battery directly.

3. For more on the QAF, visit https://www.cleanenergyministerial.org/resource-cesc/mini-grids-quality-assurance-framework/.
4. A transducer is a device that converts variations in a physical quantity (like electrical voltage or frequency at a mini grid customer's premises) to an electrical signal that can be directly measured by a datalogger.
5. For more on the QAF in Nigeria, visit https://www.tfe.energy/project/Quality-Assurance-for-Mini-Grids.
6. For more on the QAF in Myanmar, visit https://www.giz.de/en/worldwide/11988.html.
7. *Service quality* refers to attributes like the amount of electricity available, how many hours it is available each day, and the reliability of service. *Power quality* refers to physical characteristics of the voltage at a given time and location, including voltage variation over different timescales and variations in frequency. Tenenbaum and others (2014) add a third quality dimension: quality of commercial service, referring to the quality of the mini grid or the main grid's commercial interactions with customers. It could include the number of days required to connect a new customer, the time needed to resolve a complaint about billing and metering, and the time required to respond to a service complaint.

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6 What We Have Learned

"We need education in the obvious more than investigation of the obscure."

—Justice Oliver Wendell Holmes

"We know nothing for certain, but we don't know nothing."

—Erica Thompson
(Roberts 2023)

WHAT WE KNOW ABOUT ALL MINI GRIDS

Undergrid mini grids are new and rapidly evolving in developing countries, and experience with them is limited. Observations and recommendations are likely to change as practitioners gain more experience. This chapter summarizes what is known so far. The first section summarizes what is known about mini grids in general; the second section is devoted specifically to undergrid mini grids.

We begin with some general observations before moving on to promotional approaches, regulation, grants, import costs, stimulating customer demand, and the trade-offs between cost and reliability.

General observations

Mini grid developers benefit from economies of scale and standardization. It is well documented that technologies benefit from learning curves (Way and others 2022). Across a variety of mass-deployed technologies, every doubling of cumulative production leads to a fixed percentage drop in technology's unit costs of production.[1] The percentage drop in cost varies from technology to technology; generally, the drop will be greater when the underlying technology is more suitable for mass manufacturing and standardization (Malhotra and Schmidt 2020). We are starting to see the beginning of this phenomenon for the modular, non-interconnected, solar hybrid mini grids being installed by Husk Power Systems and Tata Power Renewable Microgrid in rural areas of India and Nigeria.

In India, scale has been achieved through operational and organizational aggregation of small standardized mini grid projects located in proximity to other projects operated by Husk and Tata. Husk and PowerGen Renewable are now attempting to follow a similar approach in Nigeria by standardizing and aggregating smaller non-interconnected projects located in close geographic proximity. (Refer to chapter 2.)

Standardization allows a developer to quickly scale up the number of projects that it can pursue. For example, Husk, which is now developing projects in Nigeria, has the advantage of being able to draw on 14 years of on-the-ground investment and operating experience from India that can be transferred to its new Nigeria operations. The cost advantage that comes with experience can also be seen in recent Africa-wide mini grid cost data that show lower average costs for experienced mini grid companies than for new companies. Husk has reported that it has achieved levelized costs of electricity (LCOEs) of less than US$0.30 per kilowatt-hour (kWh) at its newer sites in India (AMDA 2022, figures 5.5 and 5.6). (Refer to chapter 2.)

Investment and operating efficiencies, which lead to lower costs, can also be achieved through larger projects. In Nigeria, the currently proposed interconnected mini grids supported by the expanded Interconnected Mini-grid Acceleration Scheme (IMAS) program are projected to connect an average of 1,470 separate customers for each site. In addition, developers have also grouped several nearby sites into portfolios to achieve additional investment and operating efficiencies. These portfolios are expected to range in size from 2,500 to 4,400 connections. (Refer to appendix C.)

Mini grid developers adopt different business models. Within Sub-Saharan Africa, there is considerable variation in the mini grid business models that have been proposed or adopted. The key differences are who finances, who builds, and who operates the mini grid (Tenenbaum, Greacen, and Vaghela 2018). The variation can be seen in a more detailed comparison of the mini grids in Nigeria and the Twaake mini grids in Uganda. The mini grids in these two countries rely on business models that differ greatly in the types of commercial relations that exist between the distribution company (Disco) and the mini grid. In Nigeria, commercial dealings between the Disco and the mini grid are limited to the purchase and sale of bulk power between the two companies and the leasing of the Disco's preexisting distribution facilities by the mini grid. In contrast, in Uganda's Twaake pilot, UMEME (the country's largest Disco) and Equatorial Power (a mini grid developer) have engaged in several joint commercial activities in the non-interconnected mini grid village of Kiwumu. Equatorial Power has hired UMEME to build distribution facilities for its mini grid that meet national standards. UMEME also sells meters to Equatorial Power and provides billing services for the mini grid's customers. This setup ensures full compatibility in the metering and billing systems in the event of UMEME taking over Equatorial Power's physical facilities and operations in the future.

Equatorial Power benefits from these arrangements in at least two ways. First, UMEME, as an established and profitable Disco, can borrow money at a lower interest rate than a start-up like Equatorial Power. Second, UMEME can obtain better prices for distribution equipment than mini grid developers because it purchases equipment in larger quantities. UMEME is one of a few African Discos that is profitable. Thus, it is not likely that the full UMEME-Twaake business model could be implemented widely elsewhere in Sub-Saharan Africa. (Refer to appendix B.)

Incentives to increase rural sales differ between Discos and mini grid operators. This difference is sometimes revealed in off-the-record conversations. One of the authors (Tenenbaum) remembers the following (paraphrased) observation from an employee of a government-owned utility in Africa visiting a rural village that had recently been connected to the main grid:

> Once our lines reach the village, my job is to sign up as many connections as possible. But I'm not responsible for how much or how little these customers consume after they are connected.

In contrast, privately owned mini grid operators express a very different view:

> Once the mini grid is up and running, my job is to get both households and businesses to sign up and increase their consumption so we will have enough revenues to cover our costs and earn a profit. If we keep losing money, we'll go out of business. Unlike the government's national utility, I don't have the cushion of ongoing government subsidies after I become operational. So I don't have the luxury of not caring about sales and profitability.

In contrast, a rational Disco manager, who is also limited by the government to charging non-cost-recovering tariffs to households, will say:

> Why should I encourage my staff to try to increase sales to households in rural villages if I know that I will lose money on almost every additional kilowatt-hour that I sell in these villages?

Mini grids do a better job than main grid utilities of performing certain functions. Based on our case studies in India and Nigeria, the new generation of mini grids serving rural and peri-urban areas are generally better at the following:

- Metering and collecting from customers.
- Providing a more reliable supply of electricity.
- Adapting to the needs of customers over time by adjusting supply, hooking up new customers in a timely manner, and so on.
- Promoting demand growth by household, commercial, and industrial customers through the provision of financing for appliances and machinery. The promotion may be done by the mini grid alone or through partnerships with other entities.
- Training local staff to perform operations and maintenance functions such as customer service and technical maintenance.

Mini grids' comparative advantages suggest a possible division of responsibilities when a mini grid and a main grid utility become interconnected in a manner that goes beyond bulk purchases and sales of electricity between the two entities. (Refer to chapter 4 and appendix B.)

Mini grids can help reduce greenhouse gas emissions. This book has focused on mini grids' ability to improve access to reliable electricity, both for those who have never had electricity before and for those who are poorly served with intermittent or low-quality grid electricity. In addition to achieving more and better access to electricity, solar hybrid mini grids produce an additional benefit: reducing greenhouse gas emissions. Calculating the volume of greenhouse gases that are avoided involves a variety of variables that vary from one mini grid to another.[2] These variables include the following:

- The source of electricity or lighting sources before the mini grid. Did the mini grid customers use fossil fuel generators to produce their own electricity before the operation of the mini grid? Did they have solar home systems? Did they use kerosene for lighting?

- If a main grid source was present, for what portion of the day did it provide electricity? What was the fuel mix used to generate the main grid's electricity at the time of day that the main grid generally provided power? If mini grid customers continued with a connection to a main grid supplier, what portion of the typical customer's daily consumption of electricity was ultimately sourced from the main grid, and what portion was locally generated by the mini grid?
- What fraction of the mini grid's generation comes from renewable sources? Typically, solar hybrid mini grids generate well over half, and many generate well over 90 percent, of their annual electricity from renewable energy.
- What is the daily consumption, measured in kWh per day for a typical customer?
- If a backup diesel or gasoline generator is used by the mini grid, how many kWh of electricity are produced per liter of fuel consumed? What volume of emissions is associated with the fuel, measured in kilograms of carbon dioxide (CO_2) per liter?

Approaches to promoting mini grids

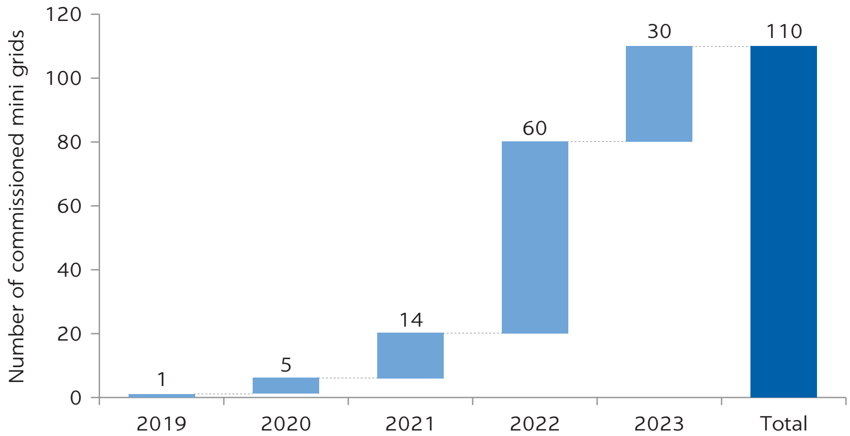
Early private sector–led results. India now has more than 600 mini grids built and operated by 13 different developers in three of its poorest states: Bihar, Jharkhand, and Uttar Pradesh. Most of these mini grids are owned and operated by Indian companies. Similarly, in Nigeria, the private developer–led approach is showing early signs of success. In June 2019, the World Bank–supported Nigeria Electrification Project started providing performance-based grants to mini grids proposed by private developers. Four years into the program, after delays caused by the COVID-19 pandemic, 110 mini grids are operating, 65 are under construction, and 216 more have been approved for capital cost grants that are likely to lead to operating mini grids.

Of the 74 private firms that have so far qualified to apply for capital cost grants from Nigeria's Rural Electrification Agency, most are Nigerian-owned companies, but at least 6 companies are foreign-owned or have a mix of foreign and domestic ownership. One of the Nigerian firms, Havenhill, has already deployed 24 mini grids; another, Nayo Tropical Technology, is operating 10 mini grids.

These early results suggest that a bottom-up, private developer–led approach has three important benefits. The first is that it can achieve rapid and significant scale-up once the regulatory and policy frameworks are in place. Tanzania, the first African country to establish such frameworks for mini grids, provides additional evidence of significant on-the-ground results. Within 9 years of putting the frameworks in place, Tanzania added 52 mini grids (Odarno and others 2017). Tanzania was widely viewed as Africa's success case, although this is probably no longer true after the Minister of Energy ordered steep drops in previously approved mini grid tariffs just before the 2020 presidential elections. In Nigeria, a pipeline of more than 600 mini grids is now under development, just 6 years after mini grid regulations were approved at the end of 2016. More important, there seems to be evidence of acceleration (refer to figure 6.1). Most of the 110 mini grids that have been constructed with help from the Nigeria Electrification Project's performance-based grants were commissioned since the beginning of 2022. Deployment tapered off in 2023 as the available grant

FIGURE 6.1

Number of mini grids, by year, commissioned under the Nigeria Electrification Project performance-based grant program, 2019–23



Source: Original figure created for this publication.

funding was fully disbursed, but a robust pipeline remains in place to be rolled out as more resources are mobilized by the World Bank and other donors.

A second benefit of the private developer–led approach is that it can stimulate growth in local small and medium domestic enterprises. As mentioned, most of the 61 companies that have applied for grants in Nigeria are Nigerian, and the foreign mini grid companies seem to be making a conscious effort to place Nigerian staff in key managerial positions within the country (refer to the Husk case study in chapter 2). The participation of Nigerian companies and personnel is more likely to lead to a sustainable, organic development of mini grids than would occur would if the sector grew through the investments of one or two foreign firms.

The third benefit is that rural energy agencies, the World Bank, and other financial institutions are learning how to fund small-scale deployment of distributed energy resources. This development marks a considerable shift that will be crucial to match the ongoing global shift from centralized generation to decentralized energy sources. (Refer to appendix A.)

An approach led by private developers may not be feasible in all countries. First, such an approach requires a minimum level of good governance and domestic entrepreneurs with experience in the electricity sector. These starting conditions were not present in the Democratic Republic of Congo; therefore, the country's government and its advisors decided that a better initial approach would be a government-initiated, highly specified zonal concession contract targeted at private companies and backed up by political risk insurance (described in appendix A).

Second, it would probably not be feasible to pursue investment in private projects in a country where the national or a regional utility has already achieved a high level of main grid electrification. For example, by 2017, Ghana had electrified more than 80 percent of communities with 500 or more residents. The remaining unelectrified communities were mostly island and lakeside communities that were difficult and costly to electrify through extension of the main grid. When a national utility has already achieved a high level of electrification and is willing to take on the additional responsibility of electrifying the few remaining unelectrified remote communities with mini grids, it is politically easier to assign the task to the national or regional utilities, which can cross-subsidize both the construction and operations of the mini grid while charging customers the same retail tariff that their main grid customers pay.

A third case is presented by countries where the national utility has a strong preference for maintaining its monopoly over retail electricity sales but very little experience with building and operating mini grids. Ethiopia and Kenya fall into this category. In both countries, the national utilities are implementing a hybrid approach. The two national utilities, the Ethiopian Electric Utility and Kenya Power, propose to hire experienced private companies to build the mini grids and operate them for a specified period. Even though a private company will be operating the mini grid for the initial period, the customers of the mini grid will be the national utility's customers from day 1. As in Ghana, it is expected that these two national utilities will charge their mini grid customers the same retail tariffs they charge their main grid–connected customers. (Refer to appendix B.)

Regulation

A detailed tariff review for individual mini grid projects is incompatible with rapid scale-up of the private developer–led approach to mini grids. If a government is serious about significantly expanding private investment in mini grids (for example, the Nigerian government's goal of 10,000 mini grids), traditional regulatory processes and tariff-setting methods designed for large national or regional utilities can quickly become bottlenecks. If a government is seeking rapid scale-up of mini grids, experienced mini grid developers will need the economies of scale offered by building batches of mini grids that are near each other and use the same technology (refer to the Husk and Tata case studies in chapter 2). To support the government's scale-up goal, the regulator must find ways to streamline its handling of applications for licenses, permits, and tariffs while still protecting mini grid customers.

There is also a need to reduce the risk that future government ministers may force national electricity regulators to renege on mini grid tariff approvals after the mini grids are up and running. Some organizations that hope to finance mini grids urge that tariff-setting rules and other regulatory procedures be embedded in large concession contracts to which the national or state governments and the mini grid companies are both formal signatories. This approach was used successfully in the privatization of distribution utilities in Romania in 2005. The concession agreement included a tariff-setting formula backed by a partial risk guarantee issued by the World Bank Group's Multilateral Investment Guarantee Agency. The guarantee mechanism provided the new private distribution owner and operator with a 5-year guarantee against revenues lost in the event the Romanian regulator failed to implement the agreed-on framework or the regulator or government revoked or modified the framework. It is unclear whether a similar approach could be used to promote mini grids, especially in countries that are not willing to offer concessions. (Refer to chapter 3 and appendix H.)

Compensation rules for early takeover. Formal regulatory rules designed to compensate mini grids for the takeover of their assets before the end of their license or permit period do not seem to have been implemented. In Sub-Saharan countries (Ethiopia, Kenya, Nigeria, Tanzania, Uganda, and Zambia) that have issued or publicly proposed formal regulatory rules for mini grids, the rules specify that the developer of isolated mini grids should receive monetary compensation for its capital investments from the main grid operator if the main grid arrives in the village or town before a specified number of years. Although these compensation rules are widespread, we have not seen any evidence that they have actually been implemented.

We can think of three reasons why the specified compensation rules have yet to be implemented. The first is that main grid operators have decided not to expand into villages served by mini grids. The second is that mini grid developers have been reluctant to test the compensation clauses and have chosen to play it safe by building in areas that are sufficiently far from the main grid so that it is not likely to arrive for many years, if ever. The third is that donor grant programs are typically designed to provide money for new capital investments by main grid utilities or Discos in villages that have never had main grid electricity service. Other donor programs also provide up-front capital grants to build new isolated and interconnected mini grid programs. However, we are not aware of any current programs that would compensate main grid utilities or Discos for payments made to mini grid owners for the takeover of their existing mini grid assets. Even if the idea of Discos compensating mini grids for incursion has not yet been tested, the fact that these rules remain on the books may well dampen Discos' enthusiasm for expanding into areas served by mini grids.

Grants and import costs

Bottom-up, private sector–led implementation, combined with prespecified performance-based grants, can be faster than the alternatives. This approach can avoid bottlenecks associated with public procurement, delegate responsibility for environmental and social compliance to private companies, and place the responsibility for customer selection, business strategy, and execution with the private sector. It allows for quicker deployment and more rapid decision-making. A developer-led approach combined with results-based financing can leverage private sector innovation and align electrification outcomes with market participants' interests, abilities, strategies, and risk appetites. These approaches are more flexible than government-led approaches that involve extensive preparation by the public sector in terms of requests for proposals, site or customer selection, technology or design elements, and deployment strategy.

However, grant programs to support private developer–led approaches also present challenges. The acceleration of mini grid deployment in Nigeria happened after an increase in grant levels under the performance-based grant program, suggesting that the initial grant levels may have underestimated the viability gaps. Even so, it is unclear whether the increase in the grant level to US$600 per connection offers more public financing than necessary to make the mini grid companies' business models viable and the cost of service affordable for consumers. It is difficult to accurately estimate the necessary adjustments for results-based financing programs, and there may be a role for competitive tendering as a benchmarking exercise. It is important that results-based financing programs retain the flexibility to adjust grant levels to market conditions. (Refer to the Wuse case study in chapter 2.)

Performance-based grants provide flexibility to the private sector, but they limit the government's ability to target specific communities or areas.

The private sector views the lack of prescribed beneficiaries or geographic areas as a positive because it provides maximum flexibility. However, mini grid companies will have an incentive to prioritize urban and peri-urban areas (that is, "the low-hanging fruit") over rural or more marginalized communities. To achieve universal access and other policy goals, the government needs tools to direct funding to priority areas and market segments. One such tool might be geographically differentiated performance-based grants. For example, In Nepal, the government provided different brackets of capital subsidy for micro-hydropower mini grids. Projects in the foothills received a lower subsidy than those in mountain areas.

Competitive procurements can provide price discovery and target priority customers. Government-initiated competitive procurement approaches include reverse auction mechanisms, such as minimum-subsidy tenders. They can be useful to harness market forces to determine the public grant funding needed to induce the private sector to connect communities that otherwise might be passed over on the grounds of unprofitability. Governments typically select the targets for such procurements and aggregate them into portfolios. The larger portfolios can attract developers and enable them to raise the necessary financing, but to date the procurements have proved time consuming and costly to set up.

Mini grids developers prefer monetary grants. The monetary grants in the World Bank's Nigeria Electrification Project seemed to be generally preferred over in-kind equipment grants provided by the German Agency for International Cooperation (GIZ) mini grid program in Nigeria. In-kind grants of equipment from donor agencies will typically have to satisfy complex and time-consuming internal procurement rules of the donor, slowing the rollout of mini grids. When donor agencies procure the equipment, they tend to pick standard items that limit opportunities for mini grid developers to demonstrate their ability to adopt cost-reducing technological and commercial innovations. This approach also handicaps experienced developers who have tested better equipment solutions in prior projects. The availability of monetary and in-kind grants from different donors in the same market, as was the case in Nigeria, may also lead to delays in project execution as developers shop between donors for better offers. (Refer to appendix B.)

In markets with high currency volatility and inconvertibility, the choice of grant currency affects the value of grants. In Nigeria, for example, disbursement of the performance-based grant in local currency created difficulties for developers seeking to source imported equipment for their projects. Initially, grants were disbursed to developers in Nigerian naira at the official exchange rate. However, developers often could not obtain access to dollars in the official government-run currency market to pay for imported equipment, so they typically had to resort to the unofficial market, where they had to settle for far more unfavorable rates. Consequently, developers lost a significant portion of the grant value (often in the range of 30–40 percent, depending on the spread between the official and the nonofficial parallel-market exchange rates).

Import duties and costs in Nigeria eat up a portion of government and donor capital cost grants. When import duties and processing fees are high, the impact of donor grants is diluted, thwarting the goal of lowering tariffs for the mini grid's customers. (Refer to chapter 2.) In effect, two parts of government are working at cross-purposes.

Stimulating customer demand

To achieve commercial viability, mini grids need to promote consumption. Mini grids that are able to charge cost-recovering tariffs are more likely to help households and businesses purchase appliances and machinery that can be put to productive use, allowing customers to save money in some ways and earn money in others, while improving the commercial viability of the mini grid. By contrast, main grid utilities that are barred from charging cost-recovering tariffs have no incentive to increase demand in rural locations. From the perspective of a Disco executive: "If I am losing money on every kilowatt-hour I sell to a customer, why would I want to increase that customer's consumption?" (Refer to chapter 4.)

Reliability and cost

Cost and reliability in mini grids involve trade-offs. Mini grids can provide very reliable electricity and often exceed 99 percent uptime if designed to do so. This high reliability is a source of pride for mini grid developers and may be insisted on by government leaders. However, high reliability comes with a cost. To meet particularly high demand for electricity, or to meet even normal demand during extended cloudy periods, solar mini grids need large backup generators or battery installations. These backup generators typically burn diesel fuel and have a cost of production that is significantly higher than electricity from solar panels. Similarly, building mini grids with battery banks large enough to cover extended cloudy periods is impractical because of the high cost of battery storage and the need to replace batteries periodically. Even a reduction of a few percentage points in electricity supply uptime for mini grids can substantially lower the LCOE from a mini grid. For example, Husk—an industry leader in driving down the cost of mini grid electricity—aims for 97 percent uptime for its mini grids. (Refer to chapters 1, 2, and 5.)

A reduction in overall system uptime that lowers a mini grid's LCOE need not mean that critical loads will experience lower reliability. To balance energy supply and demand, adjustments can be made to preserve electricity for critical customers while lowering overall system uptime and LCOE. For example, Husk's mini grids in India use smart meters that can limit or curtail individual customers' consumption to keep hospitals and banks supplied. Smart meters can act as load limiters targeting specific customers. Mini grid operators have found that rural residential customers who previously had no electricity may prefer a less expensive option that is available "most of the time" rather than "nearly 100 percent of the time." (Refer to the Husk case study in chapter 2.)

WHAT WE KNOW ABOUT UNDERGRID MINI GRIDS IN PARTICULAR

Typical engineering and economic costing models used in planning least-cost rural electrification usually conclude that grid densification and line extension to nearby areas by Discos are the most cost-effective ways to expand electricity access. The weakness of these models is that they assume that all Discos will be motivated and efficient operators. Under the standard engineering-economic models employed by governments and donors, Discos (whether government-owned or privately owned) will always be the recommended choice for grid densification and line extension to nearby areas. *In fact, most currently used least-cost planning models do not project any role at all for undergrid mini grids*. However, our findings suggest that privately owned and operated undergrid mini grids can often provide a more cost-effective and usually more reliable alternative for consumers in communities where national and local grid reliability and operational performance are poor.

Both Nigeria and India are using a private developer–led approach for undergrid mini grids but with many differences. Under this approach, the developer has considerable freedom to choose, build, and operate mini grid sites. The major characteristics of the approach as implemented in the two countries are summarized in table 6.1. The following paragraphs discuss some key differences.

Rural mini grids in India are essentially deregulated, but that is not true for Africa. Historically, India has a reputation of being overly bureaucratic and highly regulated, but that is not true for mini grids, at least not at present. Under the Electricity Act of 2003, Indian mini grids in rural areas are not required to be licensed, and their retail tariffs need not be approved by a state government regulator. Instead, tariffs are set on the basis of a willing buyer/willing seller. Under this surprising (at least for India) laissez-faire approach, it is currently estimated that private mini grid developers in three Indian states (Bihar, Jharkhand, and Uttar Pradesh) have created more than 600 functioning mini grids totaling 19 megawatts of installed capacity over the past several years.[3]

In contrast to India, in Sub-Saharan Africa, unless the mini grid is very small, developers must generally obtain a regulator's approval to build and operate

TABLE 6.1 Key aspects of the private developer–led approach to undergrid mini grids in Nigeria and India

ASPECT	NIGERIA	INDIA
Ownership of distribution poles and wires	Mini grid leases existing distribution system, investing additional amounts in rehabilitation	Mini grid developer builds and operates a new, non-interconnected distribution system separate from the Disco's system
Relationship between Disco and mini grid	Complementary	Competitive
Approvals necessary for entry into Disco service territory	Disco, community, regulator	None, except occasionally for right of way
Approvals necessary for retail tariffs	Regulator	None
Basis for tariffs	Project-by-project cost of service calculation	Willing buyer/willing seller
Permit required?	If >100 kW	Not if area is designated as rural by state government
Subconcession for defined period?	Yes	Not needed
Compensation if Disco takes over mini grid assets built by mini grid developer?	Yes, specified in the regulatory rules	Discos do not have a legal right to take over mini grid assets except through a commercial contract satisfactory to both parties
Financially troubled Discos?	Yes (privately owned)	Yes (state-owned)
Typical peak capacity (kWp) of undergrid mini grids using solar arrays	Interconnected: 395 kWp to 1 MWp Non-interconnected: 100–500kWp	30 kWp
Revenue guarantees to mini grid developer?	No	No

Source: Original table compiled for this publication.
Note: Disco = distribution company; kW = kilowatt; kWp = kilowatt-peak; MWp = megawatt-peak.

(that is, entry regulation) and for the tariffs they propose to charge (that is, price regulation). In many African countries, a mini grid developer must submit a separate cost-of-service calculation for each proposed project, unless the regulator is willing to accept a single calculation for a portfolio of proposed projects. This calculation sets an upper limit on tariffs.

Retail competition in India involves hourly decisions by customers. Mini grids built in Indian villages that are also being served by a Disco will not have a complete monopoly over the supply of grid electricity. In these villages, many residential customers will have two physical connections: one to the mini grid and one to the local Disco. When the Disco's electricity is available, residential customers typically buy from it because its tariffs are lower. In evening hours, when the Disco is unable or unwilling to supply electricity, residential customers switch over to the mini grid. This is a form of retail competition, but it is very different from the competition that exists in Organisation for Economic Co-operation and Development countries, which is based on price and environmental attributes (for example, the percentage of renewable energy in the mix) and in which customers express their preferences through their choice of suppliers.

Indian undergrid mini grids are currently reluctant to interconnect with local Discos. Husk, Tata, and most other private mini grid developers in India have decided to incur the cost of building a separate new distribution system in towns and villages where a Disco is already operating. In these communities, mini grid developers have also consciously chosen not to interconnect with the local state-owned Disco. They seem reluctant to do so for two reasons. First, India's current national regulatory framework imposes minimal regulation for small non-interconnected mini grids in rural areas. Second, mini grids view most local Discos as unreliable partners in honoring contractual commitments to supply electricity or purchase wholesale electricity.

The Indian approach is economically wasteful because it leads to the creation and operation of two separate and duplicative distribution systems. Indian mini grid developers argue that they have no other option. They report that existing Indian state-owned Discos are generally unwilling to cooperate with them. ("They don't return my phone calls and e-mails!") Even if the Discos were willing to allow mini grids to lease their distribution facilities, the mini grid developers assert that the existing distribution facilities are often in poor condition so that leasing would likely lead to many time-consuming and costly disputes. The mini grid developers point out that the success of their business model requires that they deliver electricity to their customers with a high degree of reliability. The developers argue that they do not have the time or money to deal with disputes that would be triggered by leasing poorly maintained assets.

Interconnection can lower a mini grid's LCOE, as well as its operating and capital expenses. The cost analysis in chapter 4 is based on data from six proposed interconnected mini grids in Nigeria. The six have received in-kind equipment grants and technical assistance from the Nigerian Energy Support Programme funded by GIZ (refer to appendix I). Our preliminary analysis shows that there can be cost savings for an interconnected mini grid compared with a non-interconnected mini grid serving the same customers. Lower operating and capital expenses yield LCOE savings varying from less than 1 percent up to 20 percent over the LCOE of a non-interconnected mini grid depending on (1) the cost of wholesale electricity from the Disco, (2) the cost of diesel fuel, (3) the hours per day that the Disco can provide electricity, and (4) whether the Disco is willing to be contractually obligated to provide firm electricity at the same time every day. A firm electricity contract can roughly double the LCOE savings over that of a nonfirm wholesale supply arrangement from a Disco. (Refer to chapter 4.)

Operators of interconnected mini grids must be able to deal with the risk of nonsupply by connected Discos. If an interconnected mini grid is going to establish credibility with its customers as a more reliable supplier, it must have a backstop if the Disco to which it is connected is unwilling or unable to honor its power supply commitment. A Disco may curtail supply for several reasons. Its expected upstream supply source may be physically unavailable (Nigeria). It may not have the money to pay for the upstream power (India). It may have found another customer willing to pay more for the same power. Or its management may decide that it no longer wishes to sell to interconnected mini grids.

Mini grids can deal with these risks in various ways. The mini grids in Nigeria's IMAS program plan to build extra photovoltaic batteries and more battery backup capacity; they also realize that they may need to burn more diesel fuel in backup generators when Disco electricity is not available. In effect, the IMAS interconnected mini grids have been designed to operate as if they are non-interconnected mini grids. In contrast, the Wuse market mini grid made its investment and retail tariff proposals on the assumption that the Abuja Electricity Distribution Company would be willing and able to honor its evening supply commitment at a specified bulk supply price. If it fails to honor this commitment or if the regulator approves a new, higher price for the company's sales to Green Village Electricity (the Wuse market mini grid developer), Green Village will have to seek increases in its proposed retail tariff, cut back on its expansion plans, or seek new capital cost grants that will lower its LCOE.

Discos may find it unattractive to agree to supply firm power to interconnected mini grids. They may not be willing to interconnect and offer a firm sales commitment for two reasons. First, it may not be possible for the Disco to make a firm commitment without additional capital investments in the lines and transformers that would connect it to the mini grid. The expected level of additional revenues from sales to the mini grid may not be large enough to justify this added capital investment.

Second, the Disco's electricity supply source may be an upstream generator whose availability is beyond the control of the Disco. In Nigeria, Discos are currently not allowed to own and operate generation). Accordingly, the Disco will be understandably reluctant to make a firm supply commitment to the mini grid if it runs the risk of incurring financial penalties for nonsupply if the electricity it is supplying comes from upstream generators that the Disco does not own or control. One possible solution would be for it to offer to supply electricity to the mini grid "as available." However, if power is supplied on a nonfirm basis, the mini grid's savings on operating and capital expenses will not be as large.

Discos will be more willing to do business with interconnected mini grids that can reduce the Discos' financial losses. It should not be surprising that Discos in both India and Sub-Saharan Africa are more willing to accept the creation of private mini grids in existing markets where the Discos are currently losing money. At present, Discos often lose money serving households and small commercial customers in rural and peri-urban areas. The Rocky Mountain Institute (RMI) estimates that Nigerian Discos lose US$0.21 per kWh distributed to a typical rural community owing to low collection rates, unmetered customers, and other challenges. Thus, Discos are more willing to interconnect with mini grids in rural and peri-urban areas that have the potential to reduce the Disco's financial losses than with a mini grid built to serve an industrial customer from which the Disco is making a profit.

The tariff-setting system that applies to Discos will affect their incentives to allow mini grids to operate. A privately owned Disco will have a strong financial incentive to hand over its service obligation (at least on a temporary basis) in a town, village, or marketplace if it is losing money in that location (refer to the Mokoloki, Toto, and Wuse case studies in chapter 2). If the mini grid succeeds in making the location profitable by the end of the subconcession period, the Disco will need to decide whether it should return as the retail supplier, renew the sub-license or franchise, or sell bulk electricity to the mini grid operator for resale at retail prices. The Disco's decision will depend on the relative profitability of the three options; profitability, in turn, will depend on how the regulatory rules governing retail and wholesale sales are implemented. Under traditional cost-of-service regulation (sometimes referred to as "return on invested capital" regulation), Discos will generally have a strong incentive to own distribution assets and make retail sales under this regulatory system because their profits are keyed to owning physical assets (known as the "regulatory asset base" or "rate base"). However, other factors may trump this—for example, in Nigeria, the tariffs that Discos can charge are capped. Having the additional asset of a formerly successful mini grid on their books is a liability if Discos are not able to charge tariffs that cover costs. (Refer to chapters 2 and 3.)

NOTES

1. This phenomenon is known as Wright's law. In 1936, Theodore Wright observed that the labor requirement for airplane production decreased 10–15 percent with every doubling in production. Subsequently, Wright's law has been found to apply across a range of manufactured goods—from computer chips to solar panels to beer. Its applicability to the energy sector is discussed in a podcast by David Roberts (2023).
2. Sustainable Energy for All (https://www.seforall.org/mini-grids-emissions-tool) presents a Mini-Grid Emissions Tool for calculating the reduction in CO_2 emissions that can be attributed to mini grids. Using a similar methodology, ESMAP (2022, 52) estimates that, if 217,000 mini grids become operational by 2030, they will save 1.2 billion tons of CO_2 emissions.
3. Rockefeller Foundation, Smart Power India, https://www.rockefellerfoundation.org/initiative/smart-power-india/. At present, we are not aware of reliable estimates of the number of functioning mini grids elsewhere in India.

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7 Recommendations for Mini Grid Policies and Programs

"Vision without execution is hallucination."

—Thomas Alva Edison (as quoted in Bacharach 2018)

"... policy rhetoric crashing onto the rocks of implementation."

—Satya Nadella, chief executive officer of Microsoft (as quoted in Pahlka 2023)

INTRODUCTION

Our recommendations are divided into two parts. The first section presents recommendations that are specific to undergrid mini grids (interconnected and non-interconnected). The second section provides recommendations for all mini grids. Because undergrid mini grids are one type of mini grid, the recommendations in the second section are also generally relevant for undergrid mini grids.

RECOMMENDATIONS FOR UNDERGRID MINI GRIDS

Many of our recommendations are similar to those proposed by the Nigerian Electricity Regulatory Commission in its September 2022 consultation paper (NERC 2022) and in a December 2022 white paper circulated by Nigerian mini grid developers and stakeholders (REPP, REAN, and AMDA 2022).

Policy and regulation

Set up interconnected mini grids on a voluntary basis rather than having these mini grids mandated by regulators or government officials. Interconnected mini grids will come into existence and be commercially sustainable only if a distribution company (Disco) and a mini grid developer determine that the interconnection and the resulting transactions are to their mutual advantage. Policy and regulatory mandates without financial incentives usually fail. An interconnected mini grid is unlikely to be sustainable if it fails to produce a win-win-win outcome for the Disco, the mini grid's customers, and the mini grid owners.

Adopt a light-handed approach to regulating the commercial terms and conditions of the cost and noncost elements of interconnected mini grids. Both the developer and the Disco are usually commercially sophisticated entities; they do not need the help of the regulator to protect their commercial interests. If the agreement that supports the proposed interconnected mini grid is well designed, the retail tariff should be lower than that of non-interconnected mini grids offering comparable service. If the agreement meets this standard, the regulator should offer a "no objection" response to the license or permit application (RMI 2022, 9). Conducting a separate review for each major element of the interconnection agreement could lead to a lengthy and overly complicated regulatory process that could hurt rather than help retail customers of the proposed mini grid.

Use a variety of regulatory approaches to facilitate distributed energy resource (DER) business models. Mini grids are one type of DER. Regulators should not adopt a single approach to regulating different types of DERs. Interconnected commercial and industrial (C&I) DERs are currently under development in both Nigeria and India. If an interconnected C&I DER in Nigeria serves multiple customers in an industrial park, it could be classified as a mini grid under current regulations. However, a mini grid classification could be counterproductive in Nigeria for several reasons. First, it would artificially constrain the C&I customer to a maximum generating capacity of 1 megawatt (MW) under Nigeria's current mini grid regulations—an uneconomic constraint if the size of the industrial park would support a capacity greater than 1 MW. Second, it assumes that C&I customers need the same protection by the regulator as poor households in a rural or peri-urban community. This assumption ignores the reality that C&I customers are likely to be sophisticated buyers with their own backup supply. Third, the Disco, the DER developer, and the C&I customer may have spent many months negotiating their agreement. If the regulator decides to change one element of the agreement, it creates the risk that the entire agreement will unravel. This risk does not mean that the regulator should take a totally hands-off approach. Even if it practices regulatory forbearance on the economic elements of the agreement, the regulator should still review the technical aspects of the agreement to ensure that the interconnection does not create technical problems for the main grid.

Donor and government assistance

Encourage donors to provide technical assistance to Discos as well as to mini grid developers to promote interconnected mini grids. To date, most technical assistance has gone to mini grid developers. However, Discos may also need assistance, because they may lack experience in negotiating with nonaffiliated electricity suppliers and may not understand the benefits of interconnection. Consultants' contracts should specify that they must work with both parties to seek technical and commercial outcomes that benefit both Discos and mini grid developers. The Rocky Mountain Institute (RMI) played this role in the Mokoloki mini grid project; Sustainable Energy for All did so in the Twaake project in Uganda (refer to appendix B). Continuity is also important. A senior official of the Disco should be assigned responsibility for mini grids and other DER projects, as well as responsibility for advisors embedded to support management teams.

Encourage donors to fund the collection of technical performance data on individual feeders and help Discos choose sites for interconnected mini grid projects. Data on the voltage, frequency, and availability of electricity on these feeders are often inadequate or nonexistent. Donors have funded data collection on socioeconomic characteristics of non-interconnected mini grids. A similar initiative should be undertaken to document the electrical performance of feeders for potential interconnection of Discos to current or proposed mini grid projects. Supporting Discos with such data and analytics could help them identify and prioritize communities for interconnected mini grids. Empowering Discos to proactively select areas for collaboration with mini grid developers rather than reacting to unsolicited approaches from developers may help scale up the deployment of interconnected mini grid projects.

Ensure that Discos that enter into interconnection agreements with mini grid developers are eligible for capital grants to cover the costs of additional distribution equipment to support the interconnection. Alternatively, mini grid developers should be allowed to finance such improvements. Most grants have gone to mini grid developers, but Discos may need to make repairs and purchase new equipment for the interconnection. Grant money should be made available to Discos in response to cost estimates or via prespecified capital grants on a first-come, first-served basis for interconnection projects that meet certain criteria, similar to the performance-based grants offered by Nigeria's Rural Electrification Agency to mini grid developers.

Follow-up case studies

Conduct a follow-up of the five case studies in this book. The case studies represent an early reconnaissance of undergrid mini grids. The Energy Sector Management Assistance Program (ESMAP) or another independent organization should follow up to learn whether the projects continue to be commercially and technically feasible after several years of operation. Case studies should also be conducted on a sample of the proposed interconnected mini grids supported by the German Agency for International Cooperation (GIZ) Interconnected Mini-grid Acceleration Scheme (IMAS) program in Nigeria, including those that were successful and those that were not. It would also be useful to expand the scope of case studies to include interconnected mini grids in other countries in Sub-Saharan Africa. If any of the 600+ currently operating undergrid mini grids in India become interconnected, it would be important to understand the legal, regulatory, and commercial changes that enabled the transition for both the Disco and the mini grid.

Conduct case studies of other types of interconnected mini grids. ESMAP or another independent organization should perform case studies of interconnected mini grids in market segments beyond those covered in this book. The new case studies should include interconnected DERs for public institutions (for example, universities and hospitals), C&I customers, and urban residential communities. They should include information on commercial transactions and contractual agreements with the main grid, benefits and costs for both the main grid and the mini grid, financing methods, ownership, regulation, and technical design and operation. It is important to budget for the costs that may be incurred by mini grid developers and their customers to participate in the case studies. Participants should be reimbursed for data collection and additional operational costs.[1] Downstream interconnections between alternating-current mini grids and direct-current mesh grids should also be examined.

RECOMMENDATIONS FOR ALL MINI GRIDS

Regulation and government policies

Reduce delays in acting on licenses, tariffs, environmental compliance, and safety and performance standards. In a 2020 survey of processing times for licensing and other government approvals for mini grids, the Africa Minigrid Developers Association (AMDA) found that processing times were 31 weeks in Nigeria, more than 38 weeks in Kenya, and 64 weeks in Sierra Leone. The association describes the typical mini grid regulatory processes in Sub-Saharan Africa as "glacially slow" (AMDA 2022, 15). This pace partly reflects regulatory approval processes designed for large main grid generation and transmission projects but applied with little or no modification to decentralized mini grid projects. (Refer to chapter 3.)

Move away from tariff ceilings based on individual cost-of-service reviews. Instead of reviewing the cost for each mini grid, regulators should consider implementing benchmarked price caps for both interconnected and non-interconnected mini grids. A price cap can be hard or soft, but in both instances mini grid owners can automatically receive regulatory approval for prices that are below the cap without the need for individual review. A hard benchmark means that the regulator will reject without exception any requested tariff that is above the benchmark price cap. A soft benchmark allows the mini grid owner to request a price above the price cap if the owner can justify the higher tariff. Price caps would streamline the approval process and allow for more rapid private sector development of mini grids. (Refer to chapter 3.)

Allow for automatic adjustment of previously approved mini grid retail tariffs to reflect changes that are largely beyond the mini grid operator's control. Two options should be provided to mini grid operators. The first would allow for the automatic adjustment of tariffs using an annual tariff adjustment factor calculated by the regulator. The resulting adjustment would not require a separate application for approval. Instead, the mini grid operator would simply need to notify the regulator of the tariff change. The bankability of the project would be improved if the adjustment clause were included in the bilateral or tripartite agreement between the parties. The second option would allow operators to request a tariff adjustment above the general adjustment factor if they believe their operating costs increased beyond this amount. However, this option may be time consuming and costly for the operator; it may also be denied by the regulator. (Refer to chapter 3.)

Encourage mini grid operators to offer tariffs based on time of use and reliability to their customers. These tariff structures can help mini grid operators lower their operating and investment costs and provide electricity services that better match the needs of different types of customers. Regulators and grant-giving agencies can play a role in encouraging their use. Smart meters, that can be remotely read and controlled, have made it easier to implement such tariff structures.[2] (Refer to the Tata Power Renewable Microgrid and Husk Power Systems case studies in chapter 2).

Modify Disco regulations to incentivize constructive engagements with mini grids. Traditional cost-of-service regulation, which is the norm in India and Sub-Saharan Africa, seems to create a disincentive for Discos to work with interconnected mini grids. Under such regulation, Discos make profits on invested capital and not on power sales to interconnected mini grids. If a mini grid operator succeeds in creating a profitable mini grid, a Disco will have an incentive to take over the assets to increase the size of its own regulatory asset base, earn profits, and eliminate a competitor. In the United Kingdom and the United States, the regulatory systems for Discos have been modified to move away from cost-of-service regulation toward performance-based regulation to encourage Discos to work with rather than oppose mini grids and other DERS. Regulators should examine whether performance-based regulation for Discos could encourage commercially separate interconnected mini grids and other DERs in developing countries. Doing so would support the Nigerian Electricity Regulatory Commission mandate that the 11 Nigerian Discos acquire 10 percent of their supply from mini grids and other types of DERs. (Refer to chapter 3.)

Offer blanket regulatory approval for portfolios of licenses and permits for mini grid projects with similar characteristics. Sierra Leone and Uganda have already done so, and Nigeria recently adopted a similar approach (NERC 2023). By issuing blanket approvals for portfolios of mini grids using similar technologies, regulators can create efficiencies in the approval process and allow for faster scaling of mini grid investments. Blanket approval can also help mini grid projects access commercial financing. Not all the mini grids in a portfolio will be commissioned at the same time. Regulators should routinely grant licenses or permits if the developer is willing to formally accept the terms and conditions of a previously approved blanket license or permit for comparable projects. Regulators can also establish a fast-track process that allows new projects to be deemed approved if the regulator does not respond within a certain number of days. (Refer to chapter 3.)

Allow for larger mini grids and provide clearer definitions of capacity. The current cap on the maximum size of mini grids in Nigeria (1 MW of installed generating capacity) may be insufficient for serving larger towns and C&I customers. To promote productive loads and increase economic viability, regulators should consider increasing the ceiling to 3 MW or 5 MW. No industry-wide consensus exists on how to define mini grid capacity. Some define it as the peak capacity of the mini grid's solar array, and others define it as the maximum load that can be served. The regulator needs to make it clear how it will calculate the maximum ceiling cap. (Refer to chapter 3.)

Issue permits or licenses with durations that are long enough to support project financing and allow for transfers to other entities. Permits and licenses should also provide clear criteria and procedures for transfers. Expansion of mini grids in the coming years will most likely rely on access to project financing rather than on corporate balance sheet financing. However, project financing is generally not possible unless mini grid developers are given permits or licenses that match the minimum duration of available financing agreements. According to REPP, REAN, and AMDA (2022), the minimum duration for mini grid project financing is 10 years.

Regulators should accommodate the transfer of mini grid ownership and operating rights. If a mini grid operator is failing to meet the terms of its permit or license, the regulator should encourage the transfer of the project's operating rights to a more competent operator. The regulator should also facilitate transfers if a successful operator wants to develop new projects. If the operator is performing well and wants to build new mini grids, the regulator should allow it to free up its invested capital and move on to new projects. The transfer of ownership and operating rights should be straightforward. The regulator should clearly specify the procedures and criteria that it will use in adjudicating transfer requests. (Refer to chapter 3.)

Reduce regulatory risk. An independent organization should evaluate whether mini grid regulatory risk can be lowered through guarantees or insurance. It should explore the creation of new partial risk guarantees or political risk insurance products for both privately led development and government-initiated and concession-supported projects. Many mini grids in India and Sub-Saharan Africa do not receive large concessions or sub-concessions from national or state governments; rather, they receive license or permit approvals from the regulator. It will be difficult to implement a regulatory insurance product or guarantee unless a government ministry is willing to enter into a separate contract with the mini grid developer in which the government commits to upholding the approved regulatory system. If a government is willing to enter into a broad concession contract and the contract is backed by a guarantee or insurance policy (for example, the Multilateral Investment Guarantee Agency's breach-of-contract insurance), it is important for the developer to consider the cost of premiums and whether the expected lower financing costs will outweigh the cost of premiums. It is also important for the government to consider whether providing a concession contract will lead to more private investment in mini grids at a lower overall cost. (Refer to chapter 3 and appendix H.)

Promote transparency in regulation by making stakeholder comments and license applications and approvals publicly available on the regulator's website. In many African and Asian countries, stakeholders often have no easy way of knowing what other stakeholders think about new or proposed changes in mini grid regulations except through informal back channels. This lack of transparency hurts the regulator. If different stakeholders learn that they have the same or similar views on a regulator's initial proposals, they may be able to come together to suggest modifications or alternatives that meet their needs. One way to improve transparency and facilitate stakeholder engagement is for regulators to publicly post stakeholder comments on their websites, as is the standard practice in many countries of the Organisation for Economic Co-operation and Development. Unless a stakeholder can convince the regulators that its comments must be kept confidential for commercial reasons, there is no reason to keep them secret.

The regulator should also maintain an online database of applications and approvals for mini grid licenses and permits. Doing so would help developers avoid pursuing mini grid projects that have been applied for or are being constructed by other developers. (Refer to chapter 3.)

Encourage national environmental regulators to review portfolios of mini grids. To streamline the process of approving mini grid projects, regulators should implement a system of blanket environmental approval of portfolios of mini grids using similar technologies. The Nigerian Ministry of Environment allows a developer to make a single application for up to 50 mini grids in a single state for a single payment of 50,000 Nigerian naira (US$121) and allows mini grid operators to apply using a streamlined environmental and social management plan rather than a full environmental impact statement of assessment (Nigeria, Ministry of Environment 2022). The environmental regulator should post a list of the certified environmental consultants and encourage expansion of the roster of certified consultants. (Refer to chapter 3.)

Streamline mini grid safety inspection with safeguards to reduce the risk that the system will be corrupted. Governments should consider two alternatives to on-site inspections by officials of the government standards agency: inspections by government-approved licensed professional engineers or attestation by a licensed engineer on the staff of the mini grid company. In both instances, the licensed engineer must attest to the fact that the mini grid installation meets government-specified safety standards. The agency responsible should conduct follow-up spot audits of mini grid installations that were attested to by nonagency engineers. If the mini grid fails to meet the standards attested to by the licensed engineer, the engineer may lose his or her professional license or the mini grid company may be prohibited from constructing and operating future mini grids for a specified period of time. (Refer to chapter 3.)

Adopt policies that encourage mini grid investments in unserved areas. Regulators should adopt a tiered results-based financing structure that provides additional incentives for the rollout of mini grids in priority areas, such as those affected by conflict and violence. In addition, the public sector can provide due diligence and market intelligence to the private sector to reduce the cost of project preparation and market penetration in underserved areas or market segments. Competitive mechanisms such as minimum-subsidy tenders—where the geographic scope of the intervention is defined in the tendering process—can also be used to direct the private sector to serve underrepresented populations. (Refer to chapter 6 and appendix F.)

Align distribution standards to local conditions. It is important to ensure that electricity distribution standards, including for mini grids, are appropriate for local conditions. In some cases, standards may be imported from other countries without sufficient modification for the local climate, leading to unnecessary costs. For example, poles and wires may be designed to withstand snow and ice loading in Europe or North America, but this precaution is not necessary in tropical regions. Regulators and builders should consider adopting lower-cost standards that are safe and feasible for the local environment. These innovations pertain primarily to the poles and wires that distribute electricity to customers, which are generally separate from and will not interfere with the operation of the conductors that make up the interconnection with a Disco. A study could be conducted to evaluate the technical standards for electricity distribution networks in a set of Sub-Saharan African countries and to explore options for reducing costs while maintaining safe electricity supply at levels suitable for rural customers using modern appliances. (Refer to chapter 5.)

Data and benchmarking

The World Bank or another independent organization should benchmark the impact of taxes, duties, and other import costs on mini grids' capital costs and tariffs. African mini grid developers usually import photovoltaic panels, batteries, and meters. Their "deployed at site" capital costs are affected by taxes, duties, in-country transportation costs, and "supplemental costs of doing business" (often a euphemism for bribes). One developer active in Sub-Saharan Africa has estimated that the combined effect of these import costs in some countries "comes close to doubling the landed-at-port [capital expenses] compared with the deployed-at-site [expenses]." Developers, government officials, and donors need to know how taxes and import costs compare across countries. With reductions in the costs of components and the costs associated with importing them, mini grid tariffs can be lowered, making it easier to achieve the government's goal of providing affordable electricity to underserved communities. (Refer to chapters 2 and 6.)

The World Bank or another independent organization should support the expansion of a data-sharing framework. This framework would facilitate the collection and publication of key mini grid metrics to inform decision-making by the private sector, governments, utilities, and climate financing institutions. Disaggregated data on electricity use, reliability, and consumption trends from mini grid operators that could help inform planning and policy are not widely available today. A responsible data-sharing framework that addresses issues related to data privacy, governance, standards, and sharing is needed to demonstrate to stakeholders the benefits of transparency, including providing financiers with industry- or country-level data needed to make investment decisions, such as average revenue per user and load growth over time. Electricity consumption data are needed for verification in carbon financing programs. Some mini grid programs in Sub-Saharan Africa are using data platforms such as Odyssey; those platforms could be leveraged to collect, aggregate, anonymize, and publish data from mini grid projects once stakeholders agree on a responsible data-sharing framework.

Document and compare the reliability of mini grids and the national utility. Mini grid developers and proponents like to emphasize that they offer more reliable service than main grid utilities in developing countries. This assertion needs to be better documented and benchmarked against Disco performance. Mini grids should use existing low-cost monitoring programs to document their reliability performance. Two programs could be reactivated or expanded to measure mini grid reliability. One program used in Sub-Saharan Africa, the Real-Time Electricity Supply and Quality tracker program, is no longer operational. The other is Prayas's Watch Your Power (http://watchyourpower.org/), which examines the reliability performance of Discos throughout India. (Refer to chapter 5.)

Document productive-use initiatives of mini grids and Discos and their effect on economic development. A research project should be commissioned to examine such initiatives in Africa and India, including instances in which mini grid operators have diversified beyond electricity sales into other areas (such as water purification, irrigation, crop processing, and internet access). The study could also compare the productive-use programs of mini grids and main grid–connected utilities to determine which group has a greater impact on community economic development. The resulting information could help identify successful models and best practices for promoting economic growth through access to electricity. (Refer to chapter 6 and appendix F.)

Grants

Refine the structure and size of grants. More data and more analytical work are needed to determine the appropriate levels of performance-based grants for interconnected mini grids in rural and peri-urban towns and villages. The amounts of performance-based grants are usually tied to the number of connections and to continuing service for a short period of time after the mini grid begins commercial operations. Among the questions that need to be asked are the following: Should the grants be tied to the number of validated connections or connections plus continuing service for a longer period of time? If the goal is to encourage electricity consumption, particularly for productive activity, would grants linked to the volume of consumption, rather than connections, be more effective? Should grants be given for both connections and capital costs of generation (as with Uganda's Pro Mini Grids) or just for connections (as with the Nigeria Electrification Project)? Should grant programs be designed so that the grant amount declines over time? (Refer to chapter 6 and appendix F.)

Give monetary grants rather than grants of equipment. In-kind grants from donors are often slow in arriving because they must satisfy the detailed procurement rules of the donor organization. In addition, they do not allow mini grid developers to demonstrate their competence and ingenuity in purchasing improved components for the mini grid system. (Refer to chapter 6 and appendix F.)

Give grants for mini grids in hard currency in countries with volatile foreign exchange markets. To maximize the benefits of their grants, bilateral or multilateral development organizations should give developers the option to receive grants in hard currency. Doing so will help ensure that the full value of the grants is passed through to the mini grid developer and ultimately to the end user through lower retail tariffs. In Nigeria, until recently mini grid developers received grant proceeds in local currency (naira) at the official exchange rate but then were forced to acquire hard currency (dollars) from the parallel market at a much less favorable rate, resulting in a loss of 30–50 percent of the grant value when importing necessary equipment.

Complement minimum-subsidy tenders with performance-based grants. Performance-based grants offer the private sector flexibility in developing pipelines of mini projects that match their capabilities and their ability to raise financing. These grants are especially suitable for smaller, newer market entrants because they allow such entrants to grow at their own pace. More established companies and investors may be more interested in larger portfolios of projects; minimum-subsidy tenders can help accommodate their needs. The results of these tenders can be used to set benchmarks for performance-based grants, which can be adjusted on the basis of market conditions. (Refer to chapter 6 and appendix F.)

Streamline the disbursement of grants while ensuring that doing so does not lead to corruption. If grant disbursements are keyed to milestones, the government agency administering the grant program should allow mini grid developers to self-certify that they have achieved the milestone, as has been proposed by the Rural Electrification Agency in Nigeria. To discourage false reports, the agency should conduct unannounced spot audits. Developers that lie will be required to return grant funds and should be prohibited from receiving future grants. (Refer to chapter 6 and appendix F.)

Restructure grant programs to incentivize national utilities and Discos to compensate mini grids for their investments if a national utility or Disco takes over a mini grid's facilities. Many donor grant programs in Sub-Saharan Africa provide capital grants only if the Disco builds new distribution systems in the communities to replace the distribution systems that had already been constructed and operated by mini grids. Such programs should be restructured to reimburse Discos for compensation paid to mini grids for assets not financed by grants and for initiatives undertaken to promote consumption. Without this change, Discos will have an incentive to build new distribution systems even if a perfectly adequate mini grid distribution system is already in place. Two key implementation issues are the need to consider grants that mini grid developers may have already received from donors and whether the compensation paid to developers should take account of the monetary value of the mini grid investment plus sales (as in Nigeria) or just the monetary value of the mini grid investment (as in Tanzania). (Refer to chapter 6 and appendix F.)

NOTES

1. We thank James Sherwood of RMI for bringing this issue to our attention.
2. Time-of-use tariffs incentivize consumption during daylight hours, when the cost of producing electricity is lower; reliability-based tariffs offer different levels of service to customers based on their needs.

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APPENDIX A

Government Approaches to Promoting Solar Hybrid Mini Grids

FIVE CURRENT GOVERNMENT APPROACHES TO PROMOTING SOLAR HYBRID MINI GRIDS

Private mini grid developers' choices of business models are largely determined by how the national or state government decides to promote mini grid development. This appendix examines five strategies that African and Asian governments are currently using to encourage investments in mini grids:

1. Private developers select the sites.
2. Private developer selection of sites is combined with deregulation.
3. Competitive procurement is conducted for groups of individual sites selected by the government.
4. Competitive procurement is conducted for zonal concessions selected by the government.
5. Competitive procurement is conducted to build and operate new mini grids for later takeover by a national or regional utility.

Government subsidies are usually provided under all five approaches. Table A.1 shows the approaches currently being pursued in Africa and Asia. It is limited to countries in which members of the World Bank's Global Facility for Mini Grids team have had direct or indirect advisory experience.

A government may adopt more than one approach. As the table shows, Ethiopia is pursuing three approaches, and Kenya and Nigeria are experimenting with two. Not all five approaches will be available in every country. Much depends on the country's starting conditions, particularly the attitude of the national utility or local main grid–connected distribution company (Disco) toward independent mini grids.[1] Attitudes are not forever fixed; they can change with different economic and political incentives.

APPROACH 1. PRIVATE DEVELOPERS SELECT THE SITES

Under this approach, individual domestic and foreign developers lead the scale-up. In India, this approach is sometimes referred to as "spontaneous mini grid development." Developers scout for mini grid locations, making their

TABLE A.1 Government approaches to promoting mini grids

COUNTRY	APPROACH 1: PRIVATE DEVELOPERS SELECT SITES	APPROACH 2: PRIVATE DEVELOPER SELECTION OF SITES IS COMBINED WITH DEREGULATION	APPROACH 3: COMPETITIVE PROCUREMENT IS CONDUCTED FOR GROUPS OF INDIVIDUAL SITES SELECTED BY THE GOVERNMENT	APPROACH 4: COMPETITIVE PROCUREMENT IS CONDUCTED FOR ZONAL CONCESSIONS SELECTED BY THE GOVERNMENT	APPROACH 5: COMPETITIVE PROCUREMENT IS CONDUCTED TO BUILD AND OPERATE NEW MINI GRIDS FOR LATER TAKEOVER BY NATIONAL OR REGIONAL UTILITY
Congo, Dem. Rep.				✓	
Ethiopia	✓		✓		✓
India		✓			
Kenya	✓				✓
Myanmar	✓				
Nigeria	✓		✓		
Sierra Leone			✓		
Tanzania	✓				
Uganda	✓		✓		

Source: Original table compiled for this publication.

choices on the basis of projected profitability. In many countries, developers benefit from geospatial databases developed by governments and donors that contain information on the socioeconomic and physical characteristics of potential sites. Developers still need to obtain regulatory approval for licenses or permits and for proposed tariffs for their selected sites. These approvals may be granted on a site-by-site basis or for groups of mini grids with similar physical configurations and technologies, as have been adopted in at least three Sub-Saharan African countries.

Developers often obtain capital cost grants from a country's rural electrification agency (REA) or other government entity to make their projects commercially viable. As long as a developer satisfies specified minimum technical and financial requirements, the grants are typically awarded on a first-come, first-served basis rather than competitively. The final portion of a grant is often disbursed upon verification of several months of operating customer connections, a practice known as "results-based financing" or "performance-based grants."

Regulatory approvals are given by regulators at the national or state level. A local Disco may have been previously granted a license or franchise to serve a larger geographic area that includes the mini grid sites; therefore, the developer will usually be required to obtain approval from the current Disco license holder or franchisee to build and operate the mini grid within the Disco's service area. In addition, the mini grid will usually need the regulator's approval to become a subfranchisee or sublicensee of the existing franchise or license holder. (Neither of these approvals is required in India for non-interconnected mini grids in rural designated areas, as explained in the next section.) As a condition for approval, the regulator typically requires that the mini grid sublicensee accept all obligations in the original Disco license or franchise document except tariff levels, which are likely to be higher for the mini grid. The regulator's two principal actions are thus to approve the granting of a sublicense or permit to the mini grid and to grant the right to charge specified retail tariffs. Unlike a top-down concession (described later in this appendix), the regulator's approval does not by itself constitute a contractual agreement between the regulator or the government and the developer. It is an approval rather than a contract.

Kenya

Kenya allows bottom-up development of mini grids at sites selected, owned, and operated by private developers outside a 15-kilometer buffer zone surrounding existing medium-voltage lines. This regulation would seem to eliminate the possibility of interconnected or non-interconnected undergrid mini grids. The buffer zone was specified in the 2018 Kenya National Electrification Strategy. Unlike Nigeria, as of late 2021 Kenya did not have separate mini grid regulations that specified the rules of the game for potential investors. In April 2021, the Energy and Petroleum Regulatory Authority, Kenya's electricity regulator, published a draft set of rules for public comment. The final rules were expected late in 2023. As of December 2023, they had not been issued.

Nigeria

The leading example of this approach in Sub-Saharan Africa is the performance-based grant track of the World Bank–financed Nigeria Electrification Project, which became operational in June 2019. As of October 2023, a total of 110 mini grids were operating, 65 were under construction, and 216 more had been approved for capital cost grants that are likely to lead to operating mini grids. Most of the 110 currently operating mini grids were completed after late 2021. Most of the 54 developers that have submitted site-specific project applications for performance-based grants are domestic, but at least 6 have full or at least some foreign ownership. One firm, Husk Power Systems, is operating in both India and Nigeria. The grant amount was changed from US$600 per connection (disbursed in Nigerian naira) to US$450 (disbursed in US dollars).

Advantages and disadvantages of the approach

The advantages of this approach include the following:

- Domestic and foreign developers can move quickly once the regulatory and grant systems are in place. They can replicate a standardized mini grid design at different locations to reduce capital costs.
- The regulations that specify retail tariffs usually allow developers to recover their costs. However, the regulator and developer may disagree about the values specified for various elements of the tariff-setting formulas. Developers often complain that the regulator's tariff-setting formula includes operational and cost targets that cannot be achieved, at least in the early years of operation.
- Developers have a strong incentive to stimulate electricity consumption by their customers because they bear the demand risk and know that they are not likely to receive additional subsidies beyond the amount initially granted for capital costs. Initiatives by developers to stimulate demand increase the likelihood that the mini grid will improve socioeconomic conditions in the community.
- The government is not putting all its eggs in one basket. The failure of any one developer will not compromise the overall effort.
- This approach, combined with capital cost grants, has been successful in Nigeria.
- This approach is more likely than some others to lead to the development of domestic developers.

The disadvantages of this approach include the following:

- It is not clear whether bottom-up, developer-led initiatives will be able to achieve sufficient scale to attract either local or international currency loans.
- Scale-up in connected communities may be too slow to suit the government, although evidence is growing that rapid scale-up can be achieved once the basic regulatory and grant-giving systems are in place.
- Government officials may order reductions in previously approved tariffs, especially before elections, as occurred in Tanzania in 2020 (refer to box 3.3).

APPROACH 2. PRIVATE DEVELOPER SELECTION OF SITES IS COMBINED WITH DEREGULATION

A second approach combines developer-selected sites with deregulation. In its fullest form, the developer is able to sell electricity without a license or a permit from a national, state, or provincial regulator. The developer may also be able to set retail tariffs without regulatory approval.

India provides the most prominent example of mini grid deregulation—somewhat surprisingly, given the country's reputation for being highly bureaucratic. (Chapter 3 and the Husk and Tata Power Renewable Microgrid case studies in chapter 2 describe India's approach.)

India's Electricity Act 2003 bars state electricity regulatory commissions (SERCs) from requiring that private mini grids in designated rural areas obtain a SERC license. SERCs are also not allowed to set retail tariffs for unlicensed entities. The retail tariffs charged by mini grids are thus effectively deregulated. A privately owned and operated mini grid can charge consumer tariffs on a mutually agreed-on basis—the willing buyer/willing seller approach to retail tariff-setting. This tariff-setting flexibility applies to private mini grids in both unserved and underserved areas where the mini grid is not interconnected to the local Disco. It is not clear what regulatory requirements would be triggered if the mini grid were later to interconnect.

India has more than 600 electrically isolated hybrid solar mini grids with a total installed generating capacity of more than 19 megawatts (MW). Since 2015, Smart Power India, a subsidiary of the Rockefeller Foundation, has partnered with 13 developers that have developed mini grids mostly in Bihar, Jharkhand, and Uttar Pradesh. Most are undergrid mini grids built in communities already receiving some level of service from a local Disco.

Advantages and disadvantages of the approach

The advantages of this approach include the following:

- Regulation is extremely light-handed, which makes it easier for developers to establish and scale up mini grid projects.
- The risk that the local Disco will be able to take over the mini grid's investments without adequate compensation is low if the Disco does not have an exclusive legal right to supply electricity in its service area. Any takeover of mini grid assets must take the form of a commercial agreement between the Disco and the mini grid owner.
- Commercial financing seems to be available, at least for large developers in India like Husk and Tata Power.

- In India, deregulated mini grids have been developed without any capital cost subsidies from state governments.

The disadvantages of this approach include the following:

- Mini grid development in India leads to duplicative investments in distribution systems because most mini grid developers build their own standalone systems in communities already served by a local Disco. Few mini grid developers try to reach a commercial deal with the local Disco that would allow them to lease its system, because the developers believe that the Disco's facilities are in poor condition, and they believe that it would be difficult and time consuming to negotiate with state government–owned Discos.
- Few mini grid developers attempt to interconnect to local Discos, because they fear that interconnection would trigger heavy central and state regulatory requirements.
- Few mini grid developers in Sub-Saharan Africa view Indian-style deregulation as a viable approach. Developers and financiers state that they need to know the regulatory rules of the game. Many report that the absence of regulatory rules for mini grids would be too risky.

APPROACH 3. COMPETITIVE PROCUREMENT IS CONDUCTED FOR GROUPS OF INDIVIDUAL SITES SELECTED BY THE GOVERNMENT

Government entities initiate procurements of mini grids to serve communities that meet certain government criteria. Communities in the same geographic region are usually selected in order to gain investment and operating efficiencies. Governments typically conduct competitive procurement to choose a developer to build and operate the mini grids. Interested developers typically bid on either proposed tariffs or minimum required subsidies.

Nigeria's minimum-subsidy tender

Nigeria has attempted to create a top-down approach to private investment in mini grids since 2017, when its REA, with support from the World Bank, used geo-referenced data to identify 200 potential mini grid sites in five states, each with projected demand of at least 100 kilowatts. The selection criteria included (1) sufficient load and density; (2) potential productive-use, daytime, and flexible loads; (3) supportive local and state governments; and (4) community engagement and accessibility. Government officials or consultants visited each community that met the criteria to validate the accuracy of the data.

The expectation was that the top-down, minimum-subsidy tender approach would kick-start private mini grid development in Nigeria. However, delegating decisions on design and plant dimensioning to the private sector, while using a build-own-operate model and providing public funds through a reverse auction process, presented procurement challenges that caused delays in obtaining World Bank and Nigerian government approvals. The tender was ultimately canceled. However, some variant of the minimum-subsidy tender is expected in the new World Bank–financed Distributed Access through Renewable Energy Scale-up project in Nigeria.

The original design objective was to divide potential sites into several lots in four or five states. Prequalified bidders would then be asked to bid for a minimum capital subsidy financed by the World Bank for lots of 20–40 mini grids. Potential bidders would be prequalified on the basis of their proposed business plans and their technical and financial capabilities. After prequalification, the selected bidders would compete on two selection criteria: the technical merits of their proposals and the size of their required subsidy. Developers would design, build, own, and operate the entire project, including both generation and distribution, to meet the minimum technical and service standards. The winners would be the developers whose proposals included the best combination of technical and financial evaluation and design and the lowest subsidy requirement.[2]

In February 2023, the REA, with support from the African Development Bank, launched another minimum-subsidy tender for the development of 150 solar hybrid mini grids spread across seven states and packaged into seven lots. This tender was structured as a single-stage procurement (without prequalification) using lessons learned from the previous effort. As of October 2023, proposals were being evaluated; the outcome of the second tender had not been announced.

Sierra Leone

Sierra Leone's lead program for developing mini grids is the Renewable Rural Energy Program. In its first phase (Work Program [WP]-1), a government steering committee led by the Ministry of Energy selected 54 villages for mini grid development. Because the government's highest priority was to provide reliable electricity to community health centers, all of the selected villages had to have such a center.[3] The mini grid's power-generation facilities were built on land belonging to the village health center. In return for supplying the land, the center received free electricity for up to 6 kilowatt-hours (kWh) per day. Construction of all the WP-1 mini grids was completed in 2018, under the supervision of the United Nations Office for Project Services, with funding from the United Kingdom.

In a second phase (WP-2), private companies bid and negotiated agreements with the Ministry of Energy to operate the existing mini grids built in WP-1 and to co-invest in the electrification of an additional 44 rural communities with mini grids ranging in size from 36 to 200 kilowatt-peak. (*Co-invest* means that the government owns all distribution assets and the private developer builds and owns the generation assets.) This "split-asset" model reduces the amount of capital the private developer needs to raise, because the government finances the distribution system.

Prequalified companies were given the opportunity to bid on four lots that included 54 villages in WP-1 and 44 in WP-2. Winning bidders were selected on the basis of multiple parameters. The three winners (Winch Energy, PowerGen, and Energicity) began selling electricity to the WP-1 communities in the fourth quarter of 2019.

All villages in the Renewable Rural Energy Program were preselected by the government. The three winning developers were given 20-year licenses to manage and operate the mini grids and maintain the project. The agreement specified that, at the end of the 20-year period, all project assets would be turned over to the government. This agreement can thus be categorized as a build-operate-transfer agreement in contrast to Nigeria's build-own-operate approach.

Uganda

Starting in 2016, the government of Uganda, with the active assistance of the German Agency for International Cooperation (GIZ), created two groups of rural village clusters, 25 in the north and 15 in the south. The intent was to create bundled tenders of solar mini grids that private mini grid developers could bid on. The villages were selected by the REA (now the Rural Electrification Programme) and were drawn from a group of 600 communities identified in Uganda's Rural Electrification Strategy and Plan and a 2018 master plan.

The 40 communities selected were viewed as potential sites for building and operating mini grids because doing so was less expensive than extending the main grid to these communities, which would have cost more than US$1,100 per connection. The selection of the communities for the two bundled tenders was made using Geographic Information System tools, computer-based optimization tools, and field assessments. The communities ranged in size from 35 to 200 connected households and included small and medium enterprises, and some public institutions.

After prequalification, the selected bidders were invited to submit bids based on the kWh price to serve all the communities in either the northern or southern group. The bidding documents specified that the winning firms would be required to build mini grids that relied exclusively on solar photovoltaic panels and batteries; bidders were not allowed to install diesel generators. The winning bidders were also required to supply electricity for at least 16 hours a day. Twenty-three firms submitted expressions of interest for the northern portfolio; 21 indicated interest in the southern portfolio. Four firms were short-listed for the northern portfolio and 3 for the southern portfolio. The selection of the 2 winning firms was announced in April 2019 (for the north) and June 2019 (for the south).

It was originally expected that the mini grids would become operational in 2022, but the winning bids came in at US$0.52/kWH—a price viewed as politically unacceptable. To make the projects commercially viable at a lower price, the Ugandan government and the European Union decided to increase the subsidies to the winning bidders from 40–50 percent to about 65–75 percent of the estimated capital costs for generation and batteries (US$3.70 per kilowatt-peak). Separately, the Electricity Regulatory Authority (the Ugandan electricity regulator), together with other government entities, announced a price cap of US$0.30/kWh.

Funds for the new, higher subsidy were provided by donors and disbursed by Uganda's Ministry of Finance, Planning, and Economic Development and the Ministry of Energy and Mineral Development. The subsidies per connected customer were US$210 plus the cost of a smart meter. Bidders also benefited from the fact that the distribution systems for each mini grid would be owned and financed by the government, so the winning bidders did not need to come up with financing for the capital costs of distribution. This arrangement is similar to the split-asset model used in Sierra Leone. The winning bidder, Winch Energy, the original winner in the north, was also awarded the southern tender after the originally selected bidder pulled out.

The regulatory system was streamlined to reduce regulatory costs for the winning bidders. The Electricity Regulatory Authority issued a blanket license exemption for all of the mini grids in each bundle rather than requiring separate exemption applications from each. The developers were also given a waiver of the requirement for a separate environmental impact assessment for each site.[4]

In other African countries (for example, Nigeria and Tanzania), privately owned and operated mini grids are typically created on a build-own-operate basis. In contrast, the mini grids in the Pro Mini Grid Programme in Uganda were established on a build-own-operate-transfer basis. The implementation agreements between the government and Winch Power, the selected developer, require that ownership of the mini grids be transferred back to the government of Uganda after 10 years. The government imposed this requirement as a quid pro quo for the up-front capital cost grants it provided to the winning developer. The fact that the transfer is to occur after 10 years means that the developer must charge higher tariffs than if the transfer were to take place after 20 years. It is possible that, at the end of the 10-year period, the government may offer the developer the option of operating the mini grid for an additional number of years.

Advantages and disadvantages of the approach

The advantages of this approach include the following:

- Grouping multiple mini grids in lots can lower costs. Energy Sector Management Assistance Program (ESMAP) data collected on 350 mini grids built between 2012 and 2021 show this effect. The collected data allow for a comparison of the average costs of mini grids built in portfolios versus those of one-off projects (ESMAP 2022). On average, mini grids built as part of a portfolio spent about US$80,000 less on soft development costs (project development; general administration, planning, and engineering; public relations and community engagement; permits, approvals, and licenses; and logistics and installation) than did stand-alone projects.
- Competitive procurement offers the flexibility of seeking bids based on minimum subsidy or minimum tariffs.

The disadvantages of this approach include the following:

- Meeting the detailed rules of bilateral and multilateral donors that are providing financial support for the procurement may cause delays.
- Governments may be slow in selecting the communities that developers will be asked to bid on.

APPROACH 4. COMPETITIVE PROCUREMENT IS CONDUCTED FOR ZONAL CONCESSIONS SELECTED BY THE GOVERNMENT

A *concession* is broadly defined as “any arrangement in which a firm obtains from the government the right to provide a particular service under conditions of significant market power” (Kerf and others 1998, 1). Concessions are widely used in countries where the legal code is based on French civil law. The concession approach tries to “create competition *for* a market, when competition *in* the market is not operating” (Kerf and others 1998, 1) and is usually initiated through competitive procurement for the right to serve a prespecified geographic area. In contrast, licenses or permits are the norm in countries based on English common law.

The concessionaire typically assumes “operational risks, maintenance obligations, and often investment responsibilities for the concessional asset over an agreed period” (Hosier and others 2017, 2). Under the traditional French concessional approach, the government owns these assets "from the moment that they are built, but the private operator retains full control over them until the end of the concession period" (Guislain and Kerf 1995, 2). In other cases, the legal ownership of the assets "built and financed by the private operator will remain private until their transfer to the state at the end of the concession term" (Guislain and Kerf 1995, 2). This arrangement is usually described as a build-own-transfer concession. In common law countries, the assets typically remain under private ownership even after the license period ends. This type is usually described as a build-own-operate license.

Concessions and licenses

A top-down zonal concession can be thought of as a formal contract between a government and a private operator. It specifies the rights and obligations of both parties and is designed to provide a stable and predictable regulatory regime. When used to promote mini grids, the regulatory system (for example, regulations on entry, tariffs, quality of service, exclusivity periods, and provisions related to the arrival of the main grid) and the grant system are typically embedded within the concession agreement, benefiting the mini grid developer. Because the concession constitutes a formal legal commitment by the national or state government, it is perceived as having greater credibility than if the same regulatory rules were promulgated by a national regulator under the authority of a national electricity law. In the absence of a concession, a national or state electricity regulator could grant the same approvals in the form of a license or permit, but they would not constitute a formal contractual commitment between the government and the developer.

Mini grid concessions in the Democratic Republic of Congo

The leading example of a top-down zonal mini grid concession in Sub-Saharan Africa is the planned agreement for the cities of Kananga, Mayi, and Mbuji in the Central Kasai region of the Democratic Republic of Congo.[5] If these concessions are successful, similar concessions could be awarded in other provincial capitals, with a potential total installed capacity of 200 MW. The initiative could eventually bring grid-quality electricity to 1.5 million people, with a projected investment of US$450 million over a period of several years.

The developers of the concessions will be given grants to allow them to charge affordable tariffs. The concessions could potentially be backed up by one or more risk insurance products from the Multilateral Investment Guarantee Agency covering breach of contract, expropriation, transfer restrictions, currency inconvertibility, and war and civil disturbance. (Refer to chapter 3 for a description of Multilateral Investment Guarantee Agency instruments that can reduce risk for private investors.) The Ministry of Hydraulic Resources and Electricity will award the concessions and probably act as the government guarantor that the concession agreements will be implemented as written. The country currently has no national electricity regulator. This concession is the first major project of the World Bank Group's Scaling Mini Grid initiative (www.ifc.org/scalingminigrids).

The top-down approach taken in the Democratic Republic of Congo differs from the bottom-up approach used elsewhere in Sub-Saharan Africa in four major ways. First, its mini grids will be much larger than mini grids elsewhere in Africa. It is projected that the zonal concessions will have a total installed generating capacity of close to 200 MW. In most mini grid projects developed in other Sub-Saharan African countries, the typical installed generating capacity of a mini grid is 1 MW or less. Second, the zonal mini grids are planned for 100 cities ranging in size from 50,000 to 3 million inhabitants. Existing and planned mini grids in Nigeria and India are usually designed for smaller rural communities or specified peri-urban areas with no more than a few thousand residents. Thus, the zonal concessions in the Democratic Republic of Congo might be better described as metropolitan utilities. Third, early indications are that these zonal concessions will attract large, well-capitalized international companies rather than local national firms. Fourth, the zonal concessions will include a first-of-its-kind minimum revenue guarantee: in the case of a revenue shortfall relative to “pre-agreed business plan projections,” the developer may submit a claim to the government for the difference in revenues. In contrast, in most other mini grid projects, existing and planned, the developer (not the government) bears the full risk of revenue shortfalls.

Advantages and disadvantages of the approach

The advantages of this approach include the following:

- A concession document can be used to allocate risk more precisely among the government, the developer, financiers, and customers.
- Projects may have financing requirements large enough to attract both commercial and donor financing.
- The model has a greater potential to be backed up by risk insurance products offered by the Multilateral Investment Guarantee Agency (or another insurer) that can reduce the level of risk for private developers and their investors, because a concession contract is a contract with a government entity.
- If successful, projects can be scaled up.

The disadvantages of this approach include the following:

- The approach is complex. It requires extensive documentation and buy-in from many separate domestic and international stakeholders.
- Because the pool of qualified bidders is likely to be limited to large foreign companies, the zonal concession approach does not directly promote the development of domestic mini grid developers.

APPROACH 5. COMPETITIVE PROCUREMENT IS CONDUCTED TO BUILD AND OPERATE NEW MINI GRIDS FOR LATER TAKEOVER BY A NATIONAL OR REGIONAL UTILITY

In some countries, the government has decided that the national utility should be the owner and eventual operator of some or all mini grids.[6] The utility may not want to see the emergence of retail service competitors, preferring to retain a monopoly on all retail sales of electricity throughout the country. Because the national utility may have little or no experience in building and operating mini grids for unserved communities, it may be willing to outsource the construction and initial operation of new mini grids to private companies. Typically, the tariffs charged to customers of these mini grids will be the same tariff the utility charges its urban customers. Ethiopia and Kenya have chosen this approach.

Ethiopia

With World Bank funding of US$270 million (approved in April 2021), the Ethiopian Electric Utility (EEU) will lead the engineering, procurement, and construction of greenfield solar hybrid mini grids, supported by short-term operation and maintenance contracts with mini grid developers. Upon conclusion of the operation and maintenance period, the mini grids will be operated either directly by the EEU or under a follow-up contract between the EEU and a private or cooperative operator.

Ethiopia is also expected to experiment with approaches that were attempted or are now being used in Nigeria. The first will be a minimum-subsidy tender to serve government-selected communities that show a high load potential from productive uses (Approach 3). The tender will be for lots of 20–40 communities.

The second approach will be for performance-based grants for private developers and cooperatives that submit applications to the EEU for a location of their choosing (Approach 1). If selected, the applicant will be eligible to receive a grant to meet the difference between the developer's cost of system installation and operation and the tariffs that can be charged, based on an estimate of consumers' ability to pay at the proposed site.

Kenya

Kenya will use a variation of the top-down, site-specific approach in off-grid areas in more than 100 communities in 14 northern counties, using US$40 million in funding from the World Bank. The 14 counties, which are categorized by the government as marginalized areas with dispersed populations, account for 72 percent of Kenya's land area and 20 percent of its population.

The project, which was initiated in 2017, experienced delays in acquiring land for the mini grid sites; as of December 2023, no mini grids had been constructed under this project. The plan is for the government to create six service areas or lots, each consisting of 20 or more contiguous mini grids (World Bank 2017). Each mini grid in a lot will serve about 100–700 connections with an aggregated demand of 20–300 kilowatts per mini grid. The REA and Kenya Power and Lighting Company (KPLC) select the communities. Private investment and public funds will co-finance construction of the generation facilities; public funds will be used to build the distribution network. The mini grid developer will construct the mini grid's generation and distribution systems. It will also operate both systems for 7–10 years under two contracts with KPLC. The first contract will be a power purchase agreement that obligates KPLC to pay for the electricity generated by the mini grid. The second will be a service contract to compensate the developer for the operation of the distribution grid. At the end of the contract periods, the assets will be handed over to the government of Kenya and operated by KPLC.

Advantages and disadvantages of the approach

The advantages of this approach include the following:

- It allows national utilities to retain full control over electricity distribution, whether provided through the main grid or through mini grids.
- Customers in the new mini grid communities will pay the same subsidized tariffs that the national utility charges customers connected to the main grid.

The disadvantages of this approach include the following:

- Absent considerable pressure from government, most national utilities will be reluctant to expand the use of mini grids if they are required to charge the same retail tariffs charged to their main grid–connected customers—a loss-making proposition.
- In the future, it will be more difficult for private operators to develop mini grids in other communities, because potential customers will want to be charged the same tariffs as consumers in communities served by the national utility.

NOTES

1. In its mini grid road map report, Husk Power Systems (2022) distinguishes three types of markets for mini grids: concessionary, bridge, and commercially viable markets. It posits that the size, structure, and duration of subsidies will differ across the three market types.
2. If a similar competitive bidding approach is used in the future for interconnected mini grids, it has been suggested that bidders bid on the technical merits of their proposal combined with a reverse auction on the percentage of capital investment required as a subsidy. The Disco providing the interconnection would select the winning bidders.
3. During the Ebola epidemic, the government found it difficult to fight the disease because many village-level community health centers did not have a reliable electricity supply.
4. Instead, the developers were allowed to submit a single "project brief" for all the solar/battery-based mini grids in their bundle.
5. The top-down zonal approach in the Democratic Republic of Congo is a major component of a US$600 million project approved by the World Bank's Board of Governors in March 2022. In addition to the top-down zonal concessions, the project also includes funding for bottom-up mini grids initiated by the private sector.
6. These countries are typically ones in which the national utility is experienced and reasonably well run.

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APPENDIX B

Comparison of Distribution Company Business Models in Nigeria and Uganda

MINI GRID PROJECTS IN NIGERIA AND UGANDA

This appendix compares the mini grid projects in Nigeria and Uganda (refer to table B.1).[1]

TABLE B.1 Comparison of mini grids in Nigeria and Uganda

FEATURE	NIGERIA (IMAS, TOTO, AND WUSE)	UGANDA TWAAKE PILOT (KIWUMU)
Location	Undergrid	Off-grid in a community near the UMEME grid
Ownership of Disco	Private	Private
Surplus or shortage of main grid supply	Shortage	Surplus
Disco's recent reliability performance	Poor	Good
Retail tariffs	Except in the Wuse market, mini grid tariffs are two to four times higher than the typical Disco tariff.	The mini grid tariff (US$0.203/kWh) is about the same as the Disco tariff. It is estimated that Kiwumu's retail tariffs would be about four times higher without the connection grants from the Rockefeller Foundation and the REA.
Number of Discos	11	9; UMEME is the largest Disco in Uganda, distributing over 97 percent of the power sold to end-use customers in the country.
Ownership of distribution facilities	Mixed ownership by the Disco (existing facilities) and the mini grid (new facilities). Developer leases existing facilities from the Disco.	Distribution networks are owned by the Uganda Electricity Distribution Company (the government asset owner) but leased by UMEME at 0.4 percent of the total retail tariffs billed by UMEME. At Kiwumu, UMEME did not have any leased facilities; the mini grid developer owns new distribution facilities constructed by UMEME.
Operation of distribution facilities	Mini grid	Mini grid
Construction of new distribution facilities	Mini grid	Developer hires UMEME as a subcontractor to build distribution facilities meeting the national grid standards. Mini grid operator purchases rather than leases newly constructed distribution facilities from UMEME.

(Table continues on next page)

TABLE B.1 Comparison of mini grids in Nigeria and Uganda (*continued*)

FEATURE	NIGERIA (IMAS, TOTO, AND WUSE)	UGANDA TWAAKE PILOT (KIWUMU)
Disco's legal status	Licenses	Concession that expires in 2025
Disco's financial condition	Weak	Strong
Grants	US$350/connection increased to US$600/connection from the REA (funded by World Bank).	US$1,000/connection from the Rockefeller Foundation plus a US$140–US$170/connection grant financed by the REA (now part of the Ministry of Energy and Mineral Development).
Identity of the mini grid owner	Various private companies	EP, a private company
Functions performed by the mini grid	The mini grid is responsible for sales and marketing, billing and collections, and generation and distribution.	EP is responsible for sales, marketing, generation, and distribution.
Functions performed by the Disco	The Disco leases distribution assets to the mini grid in undergrid areas where the Disco has operated; once interconnected, it will sell electricity to the mini grid.	UMEME builds distribution facilities for EP that meet the national grid code standards. In effect, EP hires the Disco to build the mini grid's distribution system. UMEME provides billing and collection services to the mini grid and expects to charge a fee for this service after the pilot program ends.
Metering	Prepaid meters typically selected and maintained by mini grids.	EP uses UMEME's standard prepaid meters, which it purchases from UMEME.
Financing of household appliances and income-generating machinery	By the mini grid or the specialized partner	Energrow, a company specializing in financing appliances for households and small businesses. EAP finances containerized micro industrial machinery (milling and drying) for the purposes of creating additional economic value in the agriculture sector. It offers a 3-year lease, during which period it jointly operates machines with local customers. Both companies have received subsidies from the Rockefeller Foundation.

Source: Original table compiled for this publication.
Note: Disco = distribution company; EAP = East African Power; EP = Equatorial Power; IMAS = Interconnected Mini-grid Acceleration Scheme; kWh = kilowatt-hour; REA = Rural Electrification Agency.

THE TWAAKE PILOT IN UGANDA

The Twaake pilot is designed to test the viability of different forms of collaboration between centralized and decentralized energy companies. This pilot is funded by the Rockefeller Foundation and implemented by Power for All and other Utilities 2.0 partners.[2]

As of December 2021, the project was operating in two villages, Kiwumu and Nyenje, in the Mukono district. In Kiwumu, Equatorial Power (EP) built a solar hybrid mini grid in what had been a nonelectrified village about 3 kilometers from the grid of UMEME, Uganda's largest distribution company (Disco). The mini grid thus started as electrically isolated, with a possible later interconnection to the UMEME grid. In May 2021, EP signed up residential and small business customers in Kiwumu to be served by the mini grid, which became operational on June 15, 2021. EP plans to eventually connect 281 residential customers and 79 small and medium village enterprises.

The Rockefeller Foundation will provide a grant of almost US$1,000 to EP for each new customer connection.[3] Apart from the Rockefeller grant, EP will also receive a separate grant of about US$140–US$170 per connection in Kiwumu from the government's Electricity Connections Program.[4]

Nyenje was already connected to and served by the UMEME grid when the pilot began. A different joint business model is being tested there—whether it is possible to create a commercially viable partnership between Energrow, an appliance and machinery financing company, and UMEME to increase the electricity consumption by existing UMEME customers.[5] Under the partnership, Energrow takes the lead in providing financing to UMEME's customers to purchase appliances and machinery. The goal in Nyenje is to examine whether it is possible to increase electricity consumption and revenues for UMEME when a specialized third party finances electricity-powered appliances and machines for UMEME's customers. Energrow is also performing a similar appliance and machinery marketing function in the Kiwumu mini grid operated by EP. During the pilot, neither UMEME nor EP pays Energrow for stimulating electricity consumption in the two villages.

In both Kiwumu and Nyenje, Energrow provides loans with terms of 6–12 months and an annual interest rate of 20 percent. East African Power (EAP) finances other specialized agro-processing equipment, such as maize milling and drying, as a service to the farming community in both villages. EAP's loan term is 3 years, with an annual interest rate of 15 percent. During this period, EAP also provides direct assistance to business borrowers to operate new machinery. If the experiment is a success in both villages, UMEME, EP, and EAP will have to decide which entity or entities will provide marketing, financing, and servicing of appliances and machines in other communities.

UMEME serves 1.7 million customers over 40,000 kilometers of 33-kilovolt to 240-volt distribution lines. It has a backlog of 250,00 connection applications (UMEME 2022). UMEME estimates that, in Kampala, it serves about 36 percent of potential connections that can be made through grid extension and densification (that is, connecting new customers in communities that are already receiving service from UMEME). The Ugandan government hopes to provide 4.1 million additional connections to the entire country by 2030 (IED 2020).[6] Currently, UMEME accepts applications only from potential customers in communities that are already served by and connected to the central grid.

OBSERVATIONS ON UGANDA, NIGERIA, AND INDIA

Starting conditions: Finances and reliability

UMEME is a private, commercially viable company[7] operating under a 25-year concession that is scheduled to expire in 2025. Its 2022 annual report shows operating profits of US$67 million on revenues of $US511 million. The company extensively uses prepaid meters. In 2019, it reported having collected 99.7 percent of billed amounts. This collection rate is in striking contrast to the much lower revenue collection rates of Nigeria's 11 privately owned Discos, most of which are commercially insolvent.

In Nigeria, mini grids exist because a Disco either has not reached a town or village or operates with poor reliability in the towns and villages that it does serve. Businesses reported experiencing more than 4,500 hours of outages in 2014 (IFC 2019). By contrast, the World Bank estimates only 61 hours of outage in Uganda in 2020. In both India and Nigeria, the current business model for undergrid mini grids continues to rely heavily on the Discos serving these communities, which continue to show poor service reliability. In areas poorly served by Discos, mini grids are able to charge three to four times higher retail tariffs than the Discos, because the mini grids can provide much higher service reliability. The obvious question is whether the current business model for undergrid mini grids would still be viable if Discos can significantly improve their reliability and continue to charge lower tariffs than mini grids.

The starting point is different in Uganda. UMEME has much higher service reliability than other Sub-Saharan African Discos. Uganda has a surplus of power, whereas most other Sub-Saharan countries face supply shortages. UMEME has also pursued other initiatives that have increased its reliability and collections. It has installed prepaid meters throughout its service area to improve collections and reduced nontechnical losses through awareness-raising programs to educate the community on the risks of illegal connections. UMEME also supports the certification and registration of electricians with the Electricity Regulatory Authority (ERA), the national electricity regulator, to ensure electrically safe connections. ERA publicly tracks UMEME's performance, publishing annual ratings for different dimensions (for example, distribution losses and new connections) of its service.

UMEME's relatively high reliability level (at least for Sub-Saharan Africa) implies that mini grids in Uganda will probably not be able to charge higher retail tariffs, especially in villages that are close to UMEME's distribution grid. ERA turned down EP's request to approve a retail tariff of US$0.29 per kilowatt-hour; instead, it approved a tariff of US$0.204, which is the same as UMEME's retail tariff. Presumably, this tariff is commercially viable for EP only thanks to the Rockefeller Foundation grant of more than US$1,000 per connection and the Ugandan government's additional grant of US$140–US$170 per connection.

Who builds? Who owns? Who operates?

Metering and billing

Unlike mini grids in Nigeria and India, which have installed meters that are different from local Discos' meters, EP has installed UMEME's meters. Doing so ensures compatibility with UMEME's existing metering system, eases a possible future interconnection with UMEME's grid, and eliminates potential issues (incompatibilities and cost increases) during interconnection. EP also uses UMEME's billing system, which allows EP's customers to make prepayments using one of four payment options.[8] When a customer makes a prepayment, the billing system does not identify EP as the seller, although it will be identified as such in the future.[9]

Mini grid developers in Nigeria and India use a different approach to metering and billing. They typically install their own proprietary metering and billing systems or ones that have been purchased from a third party other than a Disco. These systems may or may not be compatible with the Disco's metering and billing systems if there is integration in the future.

Pros and cons of the two approaches

In Uganda, EP paid about US$4 more per meter than if it had purchased a smart meter such as the widely used SparkMeter. Installing the UMEME meters offers one advantage in that they are fully compatible with UMEME's billing and collection system. Nevertheless, EP saved only about 25 percent on the capital cost of the combined UMEME metering, billing, and collection system than if it had purchased non-UMEME meters and non-UMEME billing and collection equipment to perform these functions.[10] However, using the UMEME billing system helped EP avoid the cost of installing, testing, and operating a separate billing system for its fewer than 400 customers. The equipment partnership between EP and UMEME allows EP to piggyback off existing proven equipment and software systems.

In Nigeria, the multinational mini grid developers (for example, Husk Power Systems and PowerGen Renewable) and some domestic developers install their own proprietary metering and billing systems. Local Nigerian developers, supported by the Interconnected Minigrid Acceleration Scheme (IMAS), take a different approach. They will use the meters acquired by the German Agency for International Cooperation (GIZ) on their behalf. Neither the developers nor the local GIZ staff favor the requirement to use these GIZ-acquired meters, which substitutes the technical judgment of the staff of a bilateral aid agency for that of local developers.

In India, most developers acquired their own metering and billing systems, for three reasons:

1. They do not trust the reliability of the local Disco's meters and billing systems.
2. The major developers (Husk and Tata Power Renewable Microgrid) believe their meters are of better quality and cost less than the meters used by most Discos.
3. They find that the local government–owned Discos often respond very slowly to their inquiries, if at all.

Distribution lines and transformers

In Uganda, UMEME builds low-voltage distribution networks to ensure that the mini grid's distribution system meets the national grid standards. EP subcontracts UMEME to build the distribution networks, enabling the latter to use its skilled staff and procurement system to purchase poles and wires at a lower cost. It is estimated that EP saves about 21 percent on the capital cost of the materials for these networks because it piggybacks off the lower prices that UMEME can obtain by purchasing in bulk. Once a distribution network is built, UMEME hands it over to EP, which operates and maintains the network until interconnection.

In Nigeria, the developer builds its own distribution system, although it may lease the Disco's distribution equipment (refer to the Mokoloki, Toto, and Wuse case studies in chapter 2).

Who finances?

In Uganda, as in most of Africa, mini grids receive funding from foundations, bilateral donors, and multilateral donors. Donor funding is limited and not always available when needed, potentially hindering the significant scale-up of mini grid investments in Africa, which will not be possible without an increase in commercial funding.

In Nigeria, there are some early signs of commercial financing for mini grids, at least for mini grids developed by experienced developers such as Husk and PowerGen.[11]

Between 2010 and 2018, more than 80 percent of the mini grid investment capital raised by private developers across Africa was reportedly equity-funded (Wood Mackenzie 2019). Equity capital is expensive. Developers need access to debt financing, ideally in local currencies, if they are to reduce their costs and tariffs. This type of financing is not currently an option for most mini grids.

Commercial debt financing is likely to be expensive for local developers, because they are new companies with limited track records. Mahomed and others (2020) propose that mini grid capital expenditure be financed by local Discos, which may have access to lower-cost capital if they are commercially viable. Lower-cost financing of mini grids' capital equipment by a Disco or national utility could reduce the acquisition costs of the equipment, which could be sold or leased to developers, thereby reducing mini grids' capital expenses.

This unique approach is being used in the Twaake pilot. UMEME and EP have established a commercial partnership to finance the acquisition of the mini grid's capital equipment. UMEME's financial viability allows it to obtain commercial loans at lower interest rates than would be available to EP or any other mini grid developer. In filings with Uganda's electricity regulator, UMEME estimates that its weighted-average cost of capital is 11 percent. If EP were to purchase the capital equipment on its own, it would have to finance the purchase with equity or debt financing at much higher cost. The commercial partnership reduces EP's costs of acquiring key capital equipment and ensures that the acquired equipment will be fully compatible with the rest of UMEME's system if UMEME later takes over the Kiwumu community.

Uganda is a rare case in Sub-Saharan Africa, because UMEME is a commercially viable Disco—something that is not true for most of the remaining Discos or national utilities performing distribution functions in Africa. The evidence appears to show that, unlike UMEME, distribution utilities in Nigeria and most other Sub-Saharan countries are commercially insolvent (refer to Foster and Rana 2020; Trimble and others 2016). Thus, it is not clear whether a Disco's financing of a mini grid's capital equipment would lower the grid's financing costs, despite its willingness to provide financing, unless it has access to concessional donor or government financing, in which case, it could pass on the lower-cost concessional financing to the mini grids.

Effect of starting conditions on the choice of business models

Uganda

Unlike most African utilities, UMEME appears to be making profits on its sales and providing a reliable supply of power. However, it does need help stimulating demand growth among its existing and potential new customers. Higher consumption from its customers would boost its profitability. UMEME's principal motivation in partnering with EP and EAP appears to be that these two specialized companies may stimulate demand growth at lower cost in existing and future communities served by UMEME.

Nigeria

Some Nigerian Discos are willing to allow mini grids to serve both non-interconnected and undergrid communities, as noted in chapter 2. However, lack of capital may hinder Discos from serving nonconnected communities. In addition, Discos may be unwilling to serve isolated communities if they believe that low tariffs and low consumption would lead to losses rather than profits. In communities currently receiving some service from Discos, low tariffs and poor collections are leading to financial losses for the Discos, whose service reliability is often affected by inadequate upstream supply and physical bottlenecks in the upstream transmission grid from which the Discos receive power. The Discos may be willing to allow mini grids to serve these communities, especially if the mini grids make lease payments to them (Mokoloki, Toto, and Wuse). In the case of interconnected undergrid mini grids, the Discos expect to receive some revenues from the sale of backup power to mini grids in addition to lease payments.

Post-interconnection options in Uganda

Uganda's ERA supports four types of interconnection options under its 2020 regulations for electrically isolated mini grid systems:

1. Small power producer
2. Bulk buyer from the central grid (small power distributor + some local generation)
3. Complete asset buyout
4. Generation asset removal and distribution network handover.

Of these options, the Utilities 2.0 pilot partners focus on the following:

- **Bulk buyer from the central grid (small power distributor plus some local generation from mini grid generation) (Option 2).** In this option, EP remains the mini grid network operator and continues to sell electricity to all retail customers in communities. As demand grows and exceeds the mini grid's local generation capacity, EP purchases additional power as a bulk buyer from the central grid, probably during evening hours, to meet its customers' demand. The power is purchased from the Uganda Electricity Transmission Company Limited, Uganda's designated monopoly power supplier, and is wheeled through UMEME to EP. UMEME will receive the wheeling charges. EP benefits from a bulk price for the power purchase from the central grid. The bulk price is lower than EP's evening self-supply cost, and the power allows it to continue to operate and serve its customers. UMEME benefits by selling to a single bulk customer and not having to incur the costs of dealing with hundreds of individual customers.
- **Generation asset removal and distribution network handover (Option 4.)** EP hands over the operation of its mini grid distribution network to UMEME and bears the cost of moving its generation equipment to a new location. The Uganda Electricity Distribution Company Limited—a government enterprise and owner of the vast majority of Uganda's transmission and distribution facilities—compensates EP for its distribution assets at handover. UMEME becomes the new retail supplier to what had previously been a community served by the mini grid. UMEME benefits by receiving a developed customer base, including customers who are using electricity for more intensive productive purposes. It is estimated that UMEME receives a customer base equal to about 98 percent of potential connections in the community, and these customers purchase power regularly.[12]

EP reportedly prefers the post-interconnection option of becoming a bulk buyer from transmission company combined with some continued on-site generation (Option 2). In essence, this is an interconnected mini grid similar to those that exist (Wuse) or have been proposed (Mokoloki, Toto, and Zawaciki) in Nigeria.

Another hybrid option would be to create a special purpose vehicle (SPV) consisting of UMEME, EP, EAP, and other interested investors. The SPV would own the post-interconnection system in Kiwumu. In Nigeria, the Nigerian Electricity Regulatory Commission is apparently reluctant to allow Discos to own equity in an SPV that owns generation, because the Nigerian government's policy does not permit them to do so. However, the Nigerian government might be willing to allow individual investors in the Discos to also own equity in mini grid SPVs. It is not known how the Ugandan government would view this option.

The Twaake integrated approach: Estimating total savings

The Twaake pilot aims to test the potential savings through commercial collaboration between UMEME and mini grid developers throughout Uganda. This approach is described as an integrated energy model. The potential savings from scaling up the different commercial collaborations being tested by the Twaake pilot across Africa will be estimated with a financial and engineering model that is being built by Power for All.

Future mini grid developers in Uganda should be able to save money in two ways. First, UMEME can buy distribution equipment (poles, wires, transformers, and meters) at lower prices than if mini grid operators purchased the same equipment themselves. Second, UMEME can finance these purchases at a lower cost than most mini grids. Taken together, these two factors would reduce mini grid capital costs by leveraging the utility's creditworthiness, purchasing power, and lower financing costs. A possible modeling exercise would map out the Twaake integrated energy approach for the projected development of mini grids by UMEME and private developers elsewhere in Uganda. It could provide an estimate of the cost of this particular collaborative approach and compare it to the cost of the traditional UMEME-led and -operated grid extension. However, the overarching question is whether the Twaake collaborative approach is a realistic option for other Sub-Saharan African countries that do not have commercially viable Discos.

NOTES

1. This appendix was prepared by Sumaya Mahomed (former consultant for Power for All's Twaake project) and Bernard Tenenbaum (World Bank consultant).
2. The Utilities 2.0 implementing partners are Equatorial Power (the mini grid developer), Energrow (which provides asset financing to small businesses), and East African Power (which leases micro industrial milling and drying machines for a period of 3 years). For more information on the Utilities 2.0 initiative, refer to Power for All (2021).
3. The Utilities 2.0 collaboration is a pilot that tests collaborations between UMEME and decentralized renewable energy companies. The pilot will have higher costs than commercial projects because of the small size of the sites and the newness of the partnership. The pilot is funded by the Rockefeller Foundation.
4. For more information on the program, visit https://www.era.go.ug/index.php/resource-centre/regulatory-instruments/policies.
5. Uganda has a surplus of supply. The government has urged all stakeholders to participate in the experimental business model.
6. The Ministry of Energy and Mineral Development developed a draft National Electrification Strategy in 2020 to identify how the country can achieve 100 percent electrification by 2030 (IED 2020).

7. UMEME is one of only two commercially viable Discos in Sub-Saharan Africa; the other is in Seychelles (Blimpo and Cosgrove-Davies 2019).
8. UMEME's customers can pay via Stanbic Bank or with mobile money provided by the mobile phone companies Ezee Money and Pay Way.
9. This feature was not implemented in Kiwumu, because of time constraints and the cost associated with changing UMEME's back-end billing system.
10. UMEME does not buy smart meters in bulk. Using UMEME's meters increased the project cost by 4 percent.
11. In 2021, PowerGen and CrossBoundary announced a US$9 million mini grid construction deal in partnership with EDFI ElectriFI, Oikocredi, and Triodos Investment Management. The deal will finance the construction of 28 mini grids (Church 2021).
12. In rural areas, UMEME has typically signed up less than half of the possible customer connections per site. If UMEME takes over Kiwumu, it is projected to acquire twice the number of connections that it achieves through its traditional grid extension approach.

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APPENDIX C

Nigeria's Interconnected Mini-grid Acceleration Scheme

DESIGN AND GOAL OF THE INTERCONNECTED MINI-GRID ACCELERATION SCHEME

The Interconnected Mini-grid Acceleration Scheme (IMAS) is a donor-supported initiative to promote interconnected mini grids in Nigeria.[1] It is jointly managed by Nigeria's Federal Ministry of Power and the Rural Electrification Agency (REA) and receives support from the Nigerian Energy Support Programme (NESP), a technical assistance program co-funded by the European Union and the German government. IMAS is implemented by the German Agency for International Cooperation (GIZ), in collaboration with the German Federal Ministry of Power. Its main objective is to test models of interconnected solar hybrid mini grids proposed by competitively selected local developers in rural areas. IMAS's goal was to provide 25,000 customers (approximately 125,000 people) with access to electricity by September 2021.[2]

SELECTION OF DEVELOPERS

From mid-2019 to mid-2020, IMAS conducted competitive procurements in Nigeria. Sites were grouped into lots, each covering a region (refer to table C.1). Mini grid developers were selected through a three-stage process:

1. **Preliminary check.** Project staff confirmed that submitted bids included all documents required by the Call for Proposals, disqualifying incomplete bids.
2. **Eligibility check.** Submitted bid documents were checked against eligibility criteria. Proposals either passed or failed at this stage.
3. **Selection.** Eligible proposals were assessed and ranked for each lot (0–999 points). The proposal with the highest score was selected as a lot's winner.[3]

Eligibility was determined and winners selected on the basis of the following main criteria:

- Be well-established in Nigeria, and comply with all laws and regulations.
- Be able to attract third-party finance.

TABLE C.1 Projects in the IMAS and MAS programs, Nigeria

PROJECT/AREA	DEVELOPER	LOCATION
IMAS (Interconnected Mini-grid Acceleration Scheme)		
Abuja	GVE Projects Ltd.	Kogi
Benin	Rubitec Solar	Ondo
Ibadan	Nayo Tropical Technology	Kwara
Ikeja	A4&T Power Solutions	Lagos
Jos	ACOB Lighting Technology	Plateau
Kaduna	Sosai Renewable Energies	Zamfara
Port Harcourt	Darway Coast Nigeria	Cross River
MAS (Mini-grid Acceleration Scheme)		
North Central	Nayo Tropical Technology	Niger
Southwest	Havenhill Synergy Ltd.	Osun
Southeast	GVE Projects Ltd.	Anambra
South South	ACOB Lighting Technology Ltd.	Delta, Edo

Source: Integration Consulting Energy and Environment GmbH.

- Be capable of implementing mini grid projects.
- Have prepared a sound proposal that meets the technical specifications.

Selections of the two IMAS schemes led to 11 awards, with an additional 7 projects receiving awards by June 2023, bringing the total to 18.[4]

PROJECT MODEL

Developers will design, partially finance, build, and operate interconnected mini grids under a concession model in the franchise areas of Nigeria's privately owned and operated distribution companies (Discos). As of June 2023, none of the mini grid projects under the IMAS program was operational, but construction was supposed to commence soon. A few of the projects were expected to become operational by the end of 2023.

In-kind grants

The IMAS projects will receive €8 million in in-kind grants from the REA (in the form of diesel generators, poles and wires, smart meters, and productive-use equipment),[5] with support from NESP.[6] Developers are also permitted to receive in-kind grants for generation equipment, such as diesel generators deployed as backups to the solar hybrid system. Financing for photovoltaic panels and backup batteries is anticipated to be provided by developers, equity investors, and loan providers; the in-kind equipment grants are expected to have a value of US$350–US$400 per connected customer.

Technical assistance

Under IMAS, the REA, with NESP's support, is providing extensive technical assistance both before and after mini grids become operational. This technical assistance, provided free of cost, includes the following:

- Remote and on-site mapping of targeted locations
- Demand modeling, including load and demand growth scenarios
- System design, including generation sizing and distribution network planning
- Financial modeling and the preparation of an information memorandum for potential investors (expected to support access to finance by mini grid developers)
- Acquisition of third-party financing and regulatory approvals
- Support during project implementation, including project construction and commissioning
- Support during the early stages of operation, including system performance monitoring and demand simulation.

NOTES

1. Another initiative, the Mini-grid Acceleration Scheme (MAS), was created to support off-grid mini grids and provided awards to four local developers. MAS was converted to an interconnected mini grid scheme as a result of the launch of the Nigerian Electrification Project, funded by the World Bank and African Development Bank and implemented by the REA, which supports off-grid mini grids. MAS and IMAS are administratively separate but are collectively referred to as IMAS because they share the common goal of promoting interconnected mini grids. This appendix adopts the spelling conventions used in the official IMAS documents.
2. The initial targets were reduced and the deadline for the commissioning of the awarded projects extended as a result of the COVID-19 pandemic.
3. For MAS, there were six lots, one per geopolitical region. For IMAS, there were 10 lots, 1 per distribution company (Disco) region (excluding the Yola Disco, which did not express interest in taking part in the scheme).
4. The Eko, Kano, and Enugu Disco region lots under IMAS and the Northwest and Northeast lots under MAS received no eligible offers.
5. By contrast, the World Bank and the African Development Bank provide monetary grants to the mini grid projects selected under the Nigerian Electrification Project. Under the project's performance-based grant component, the World Bank has agreed to provide monetary grants of US$600 per connection.
6. The initial amount of €9 million was reduced by €1 million, which was redirected to support the government's COVID-19 efforts by procuring a solar hybrid system for the Nigerian Centre for Disease Control and the National Reference Centre in Gaduwa. Separately, the initial connection target under IMAS was reduced. The change increased the size of the per-connection grant, which now stands at €320 per connection.

APPENDIX D

Definitions of Mini Grids

SOME CURRENT DEFINITIONS

Mini grids have been defined in various ways, as outlined in table D.1.

TABLE D.1 Definitions of mini grids

SOURCE	DEFINITION
US DOE (2012, 84)	A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected and islanded mode.
ESMAP (2022, 2)	Electric power generation and distribution systems that provide electricity to just a few customers in a remote settlement or bring power to hundreds of thousands of customers in a town or city. They can be fully isolated from the main grid or connected to it but able to intentionally isolate ("island") themselves from the grid. A mini grid has to serve multiple customers.
Tenenbaum and others (2014, 371)	A small electricity generation and distribution network, typically with a generation capacity of less than 10 MW. It may be physically separate (isolated) from the area's main grid. Alternatively, it may be connected to the main grid but have a separate owner and operator that performs commercial functions (metering, billing, and collections) and technical functions (repairs, maintenance, and replacement of distribution facilities) that would otherwise be performed by the main grid operator.
IRENA (2016, 2)	Integrated energy infrastructure with loads and energy resources. Mini grids can be categorized based on their interconnection to the grid and the level of service provided.
SEforALL (2020, 5)	A group of interconnected distributed energy resources (DERs) plus loads or a single DER plus load(s) within clearly defined boundaries. The main feature of mini grids is their ability to operate independently, enabling them to be set up in remote locations that the main grid does not reach. Mini grids can be totally isolated or connected to a grid.
Marnay and others (2015)	Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded.
RMI (2018, 10)	Stand-alone power generation systems of up to 1-MW capacity that provide electricity to multiple consumers through a distribution network. They may remain isolated, convert to an interconnected mini grid by connecting to the Disco's network, or be developed as an intentionally interconnected system. Mini grids differ from embedded generators, which are independent power plants connected to the centralized grid at the distribution level. Mini grids tend to have a smaller capacity than embedded generation and are also intended to operate independently from the local distribution licensee.

(Table continues on next page)

TABLE D.1 Definitions of mini grids (*continued*)

SOURCE	DEFINITION
Greacen (2020, 4)	A low-voltage distribution grid that receives electricity from one or more small generators (usually renewable) and supplies electricity to a target group of consumers, typically including households, businesses, and public institutions. A mini grid can be fully isolated from the national grid or connected to it, but if it is designed to be connected to the national grid, it must also be able to intentionally isolate ("island") from the grid.
NERC (2016, section 3)	Any electricity supply system with its own power-generation capacity that supplies electricity to more than one customer and can operate in isolation from or be connected to a distribution licensee's network. Within this regulation, the term *mini grid* is used for any isolated or interconnected mini grid generating 0 kW–1 MW of power.
AMDA, Economic Consulting Associates, and Odyssey Energy Solutions (2020, 12)	Stand-alone energy systems that offer grid-quality electricity for an entire community, its businesses, and even small-scale industry.

Source: Original table compiled for this publication.
Note: AMDA = Africa Minigrid Developers Association; DOE = Department of Energy; ESMAP = Energy Sector Management Assistance Program; IRENA = International Renewable Energy Agency; kW = kilowatt; MW = megawatt; NERC = Nigerian Electricity Regulatory Commission; RMI = Rocky Mountain Institute; SEforALL = Sustainable Energy for All.

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APPENDIX E

Differences between Mini Grids in Developing and OECD Countries

OVERVIEW

Mini grids in developing countries and those in Organisation for Economic Co-operation and Development (OECD) countries differ in their reason for existence (or motivation), the customers they serve, and their interconnections with the main grid.[1]

Developing countries

Motivation

Historically, the principal motivation for installing a mini grid was to provide households and businesses in isolated communities with first-time access to grid-quality electricity. Most mini grids are electrically isolated and located in rural communities, but interest is growing in developing interconnected mini grids to improve service reliability for customer groups in rural, peri-urban, and urban communities connected to but poorly served by the main grid.

Customers served

Most mini grids are built to serve multiple customers (residential, institutional, commercial, and industrial) in a single geographic location.

Interconnection to the main grid

Until recently, most mini grids were electrically isolated, but interest is growing in interconnected mini grids to lower operating and capital costs and to increase revenues through sales to distribution companies (Discos) and other main grid connected entities.

OECD countries

Motivation

The principal motivation for mini grids has been to make existing electricity supply more reliable. Utilities in many OECD countries have achieved (at least) 99 percent reliability; some customers (such as data centers and hospitals) need even more reliable supply. Mini grids serving those customers are sometimes referred to as "nonexport, self-service" mini grids.

Large users (commercial, industrial, and institutional users) have also built mini grids to reduce payments that they would otherwise have to make to local utilities for demand charges (that is, tariff payments based on peak demand). An increase in the number of extreme weather events has led local governments to invest in mini grids to ensure continued function of critical government and private facilities (for example, hospitals, police stations, fire stations, sewage treatment plants, jails, and supermarkets) if the main grid cannot operate for days or weeks. In the United States, an extreme weather event is one that causes US$1 billion or more in damages. Between 1980 and 2000, the United States saw an average of seven extreme weather events per year. That figure more than doubled, to 16, between 2016 and 2020.[2]

Microgrid development in OECD countries is also driven by the growing use of distributed generation, mostly solar, and the increasing use of batteries in conjunction with solar as a result of constraints imposed by distribution utilities on exported power. Once a generation and distribution system has solar plus storage, the extra cost for islanding for reliability during outages is small. Mini grids that can help reduce utility system constraints and defer investments in distribution from the main grid (that is, mini grids that serve as a nonwire solution to capacity constraints on existing distribution and transmission systems) are also attracting growing interest.

Customers served

Mini grids have traditionally been built for single businesses or institutions (for example, universities, hospitals, and industrial or commercial installations) or for multiple businesses or institutions in one location (sometimes called a *campus*) with a shared need for robust power supply. In most US states, mini grids are prohibited from serving noncontiguous installations in the legal franchise awarded to local Discos. The typical utility franchise prohibits a mini grid or other entity from owning infrastructure that crosses public rights of way, such as a public road (the "over-the-fence" prohibition). It also restricts "electricity customers from serving as an electricity supplier to other customers" (Roberts 2020). To bypass the over-the-fence prohibition, multicustomer mini grids or single customers with multiple noncontiguous loads usually include the local distribution utility as a joint owner of the mini grid. In some locations, mini grids are prohibited from reselling electricity purchased from the local Disco to their customers.

Interconnection to the main grid

Most mini grids in fully electrified countries are interconnected to the main grid from the very first day of operation, although many are also capable of operation while being electrically isolated or islanded. Exceptions are the approximately 200 remote mini grids in Alaska, which has no main grid, and mini grids in remote parts of Australia, where mini grids have always operated in islanded mode.

NOTES

1. In OECD countries, *microgrid* is the more commonly used term. For ease of exposition, we use the term *mini grids* to refer to both microgrids in OECD countries and mini grids in developing countries. Because mini grids in the United States are well documented, we draw liberally from the US experience. An online database of US microgrids, updated monthly, can be found at US Department of Energy, "Microgrid Installations," https://doe.icfwebservices.com/microgrid.
2. National Centers for Environmental Information, "Billion-Dollar Weather and Climate Disasters," https://www.ncei.noaa.gov/access/billions/.

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APPENDIX F

Grants and Concessional Financing for Mini Grids in Nigeria

OVERVIEW

Developers of interconnected mini grids in Nigeria obtain financial support for their projects in the form of grants, subsidies, or concessional debt from Nigeria's federal government and international development partners, such as the German Agency for International Cooperation (GIZ), the World Bank, the Agence Française de Développement (AFD), and the European Union. Three programs that have provided support funds are described in detail in this appendix, in part to demonstrate how similar schemes might be structured in other countries of Sub-Saharan Africa. The programs described here are the Nigeria Electrification Project (NEP), the Solar Connection Intervention Facility of the Central Bank of Nigeria (CBN), and AFD's Sustainable Use of Natural Resources and Energy Finance (SUNREF) Nigeria project.

THE NIGERIA ELECTRIFICATION PROJECT

The NEP is the Nigerian government's flagship rural electrification initiative. It is capitalized with US$350 million from the World Bank and US$200 million from the African Development Bank and implemented by Nigeria's Rural Electrification Agency (REA).

The NEP aims to "increase access to electricity services for households, public institutions, and underserved micro, small, and medium enterprises" (Exel 2020, 10), including a sizable allocation for private sector–led mini grid development through minimum-subsidy tenders, a performance-based grant (PBG) program, and the electrification of public health facilities as part of a COVID-19 response. The World Bank–supported part of the program has a budget of US$150 million for mini grid development. It targets the electrification of 300,000 households and 30,000 micro, small, and medium enterprises, and includes US$48 million for a PBG program that initially provided grants of US$350 (disbursed in Nigerian naira equivalent) per electricity connection to eligible mini grid projects on a rolling basis.[1] In October 2021, the grant amount was increased to US$600 per connection (still disbursed in naira), and changed again in October 2023 to US$450, disbursed in US dollars.

NEP's performance-based grant program

Eligibility for PBGs was initially limited to solar and solar hybrid systems in unserved areas, defined in the 2016 Nigerian mini grid regulations as areas without existing distribution systems that have less than 1 megawatt of generation capacity. The decision to restrict the initial focus of the PBG program to unserved areas was a strategic choice rather than a necessity, because the legal agreement between the World Bank and the government of Nigeria for the NEP clearly specifies that the project scope includes unserved as well as underserved areas.[2] The REA and the World Bank subsequently opened up the PBG program to interconnected mini grids and are assessing what, if any, additional changes to the program design and requirements are warranted—for example, should the same connection grant be offered to interconnected mini grids, or should a different grant amount specifically targeted for interconnected mini grids be offered?

Application for PBGs is a three-stage process that includes a one-time qualification step for the developer, followed by site-specific technical applications for individual mini grid projects that the developer has identified and developed.[3] In the qualification stage, the developer must demonstrate that it is eligible and qualified (both technically and financially) to enter the PBG program. Applicants must also submit a business plan detailing the company's business model and corporate financial plan. In the site-specific technical application stage, qualified applicants are invited to submit their grant applications for specific sites.[4] Once a developer has qualified to enter the PBG program and its site-specific technical application for a particular mini grid project has been approved, it signs a grant agreement with the REA. The grant agreement documents the number of electricity connections to be achieved by the project, the timeline for completion, and other applicable terms and conditions (refer to figure F.1).

FIGURE F.1

Application steps for performance-based grants

Qualification

- **Eligibility**: World Bank eligibility and absence of conflicts of interest
- **E&S compliance**: requirement to show compliance with World Bank and REA safeguards
- **Technical capacity**: relating to the experience of the Applicant in developing and operating mini grids
- **Financial capacity**: relating to the Applicant's capacity to secure financing (equity and debt)
- **Business plan**: Applicants will have to submit a business plan that complies in form and substance with the template.

Site specific

- Site location and targeted number of connections in 21 months
- Generation design
- Distribution design
- Evidence of compliance with minimum technical requirements
- Evidence of regulatory compliance
- Proof of compliance with E&S and other program requirements

Grant agreement signing

- Standardized and non-negotiable
- Grant period: **21 months**
- Grant will terminate after **12 months** if the Grantee has not commissioned the mini grid
- Grant agreement contains clauses on enforcement of program requirements (service standards, minimum technical specifications, and E&S requirements), and on reporting requirements

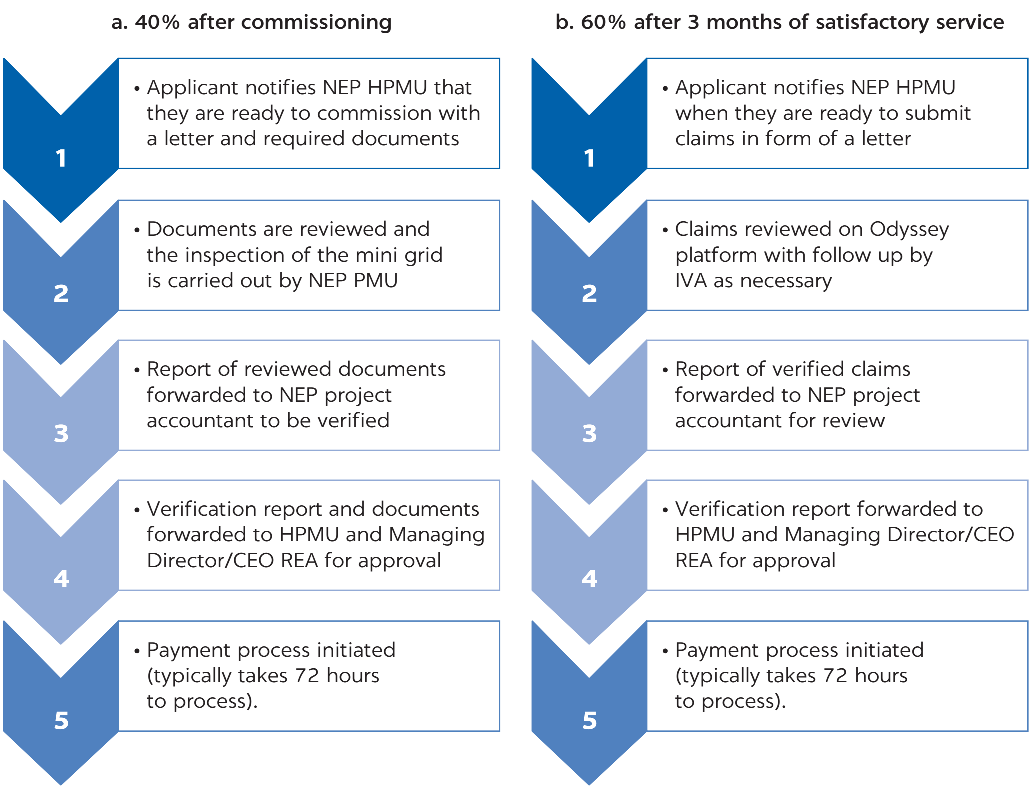
Source: Reproduced from REA 2020.
Note: E&S = environmental and social; REA = Rural Electrification Agency.

Once the developer constructs and commissions the mini grid, the PBGs are disbursed after a successful commissioning test and upon verification that customers have been connected to the network and provided satisfactory service for at least 90 days. Developers can claim PBGs as projects and make additional connections (up to the number specified in the grant agreement) within the 21-month validity period of the grant agreement. Originally, grants were to be disbursed only after verification of 90 days of satisfactory electricity service delivery to end users. This condition was changed because of the impacts of the COVID-19 pandemic on the cash flow and bottom line of mini grid operators. The disbursement schedule was revised to allow for partial payment of PBGs at the commissioning of a mini grid, with the remainder disbursed according to the original schedule.

Figure F.2 illustrates the two-step verification and grant-disbursement process, which is also expected to apply to interconnected mini grids now that they are eligible to participate in the PBG program. Forty percent of the grant amount for the number of connections achieved at commissioning may be disbursed after completion of the steps listed in figure F.2, panel a. The remaining 60 percent will be disbursed after verification of satisfactory service by an independent agent and review and approval by NEP and REA staff. For connections achieved after commissioning, 100 percent of the grant amount will be disbursed after verification of 90 days of satisfactory electricity service delivery.

FIGURE F.2

Verification and disbursement process for performance-based grants



Source: Reproduced from REA 2020.
Note: CEO = chief executive officer; HPMU = Head of Project Management Unit; IVA = independent verification agent; NEP = Nigeria Electrification Project; PMU = Project Management Unit; REA = Rural Electrification Agency.

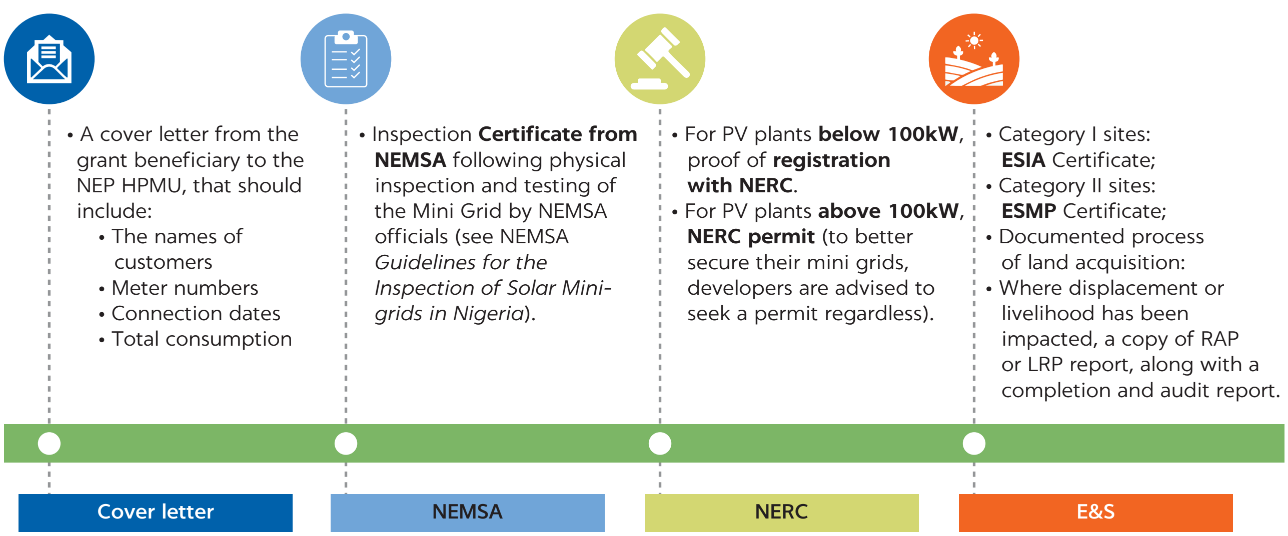
To proceed to commissioning, developers must demonstrate compliance with all applicable safety, regulatory, and environmental and social safeguard requirements. Figure F.3 shows the documentation that must accompany the letter requesting inspection of the mini grid and commissioning test, which triggers the disbursement of the first tranche of the PBG. The documentation includes an inspection certificate from the Nigerian Electricity Management Services Agency, a registration or permit from the Nigerian Electricity Regulatory Commission, if not submitted earlier in the application process, and an environmental and social management plan or impact assessment, if not submitted earlier in the application process.

After disbursement of the first tranche of the PBG, subsequent claims for payment based on connections achieved and satisfactory electricity service delivery must be made on the Odyssey tracking platform, which the REA uses to administer and manage the program. An independent verification agent has been contracted to review such claims and smart meter data and to physically verify connections, when necessary, on a sample basis.

The REA and the World Bank have partnered with Odyssey Energy Solutions to build a big data software platform for the NEP. The platform enables the development, financing, and management of distributed energy systems at scale; it is designed to facilitate the rapid deployment of mini grids and solar home systems through efficient, low-cost, results-focused financing.[5] This end-to-end tool suite supports the NEP with data management through a centralized database (which can be used to prepare and share mini grid feasibility studies with participants in a tender, for example); tender administration, with the implementation of results-based financing programs, including the PBG program for mini grids; and project monitoring and tracking of key metrics for evaluation purposes. The PBG program relies on the Odyssey platform to both manage and evaluate proposals for mini grid projects from the private sector. Odyssey helps

FIGURE F.3

Verification and disbursement requirements for performance-based grants



Source: Reproduced from REA 2020.

Note: For the NEMSA guidelines document mentioned in the figure, refer to NEMSA (2020). E&S = environmental and social; ESIA = environmental and social impact assessment; ESMP = Environmental and Social Management Plan; HPMU = Head of Project Management Unit; kW = kilowatt; LRP = Livelihood Restoration Plan; NEMSA = Nigerian Electricity Management Services Agency; NEP = Nigeria Electrification Project; NERC = Nigerian Electricity Regulatory Commission; PMU = Project Management Unit; PV = photovoltaic; RAP = Resettlement Action Plan; REA = Rural Electrification Agency.

validate technical designs and process documentation, for example, and verifies customer connections and electricity service delivery to trigger the disbursement of grant payments.

Changes to NEP's original performance-based grant program

The REA announced three major updates to the NEP PBG program at a roundtable meeting with mini grid developers on October 15, 2021. The changes included (1) an expansion of program eligibility criteria to include interconnected mini grids, (2) an increase in PBGs from US$350 to US$600 per connection, and (3) a revision of the grant-disbursement schedule to allow for partial disbursement of grants against achievement of earlier milestones. In October 2023, the PBG was set at US$450 per connection and was disbursed in US dollars.

Expanding eligibility to include interconnected mini grids

Eligibility for the PBG program was initially restricted to mini grids in unserved areas, which were, by definition, isolated. The 2021 update allows for interconnected mini grids to apply for the same PBGs as isolated mini grids.

Some additional conditions apply to interconnected mini grid projects. They must have a tripartite contractual agreement between the developer, the community, and the distribution company (Disco) in whose territory the project will be located. The Nigerian Electricity Regulatory Commission provided a model tripartite agreement in its 2016 mini grid regulations. The developer and the Disco must also sign a service-level agreement specifying the time and duration of electricity exchange between the mini grid and the main grid (and any associated penalties for nonperformance).

Changes in the value and currency of performance-based grants

PBGs were increased from US$350 to US$600 per connection, for both isolated and interconnected mini grids. The larger grant will apply to all new grant agreements, as well as to existing grant agreements for which more than 70 percent of the total grant value has not been disbursed. For projects in the second category, addendums to the grant agreements need to be signed to reflect that remaining disbursements under the agreements will be at the higher per-connection rate (which will not apply retroactively to connections already made). Projects are nevertheless expected to comply with the tariff regulations designed for mini grids, which mandate mini grids with permits to maintain tariffs under the ceiling determined by the multiyear tariff order (MYTO) calculation tool. In doing so, developers eligible for the higher grant might have to reduce their tariffs to comply with the permissible tariff ceiling factoring in the grant's value.

The US$600 per connection figure is a bit deceptive. The CBN decided that developers would be allowed to receive the NEP grant in naira (N) only at the official exchange rate (N440 = US$1 in the fourth quarter of 2021) instead of at the open market rate (sometimes called the *parallel market rate*) of N570 = US$1. However, if the mini grid developers who received the grants wanted to import equipment that needed to be paid for in dollars, they could acquire the dollars only at the open market rate. These exchange rate differences meant that developers effectively lost 30–50 percent of the value of the grants. As of October 2023, this issue no longer exists because disbursements (at US$450 per connection) are in US dollars.

Tying disbursements to earlier milestones

The PBG program initially called for the disbursement of the entire grant upon verification of customer connection and 3 months of satisfactory service delivery. Mini grid developers complained that this requirement was not workable because they needed access to the grant money at an earlier stage to move their projects to operation. With the onset of COVID-19, expedited disbursement of 40 percent of the grant at commissioning (for the connections achieved at commissioning) was permitted. The remaining 60 percent would be disbursed 3 months after commissioning, upon evidence of satisfactory service.

A later update in 2021 introduced an even earlier payment milestone: delivery of goods to sites. The REA will need to verify that certain equipment (photovoltaic panels, inverters, batteries, and meters) have been delivered to project sites. The program will then authorize the disbursement of 40 percent of the grant for the number of meters at the sites (a proxy for the number of connections expected to be made).

At the next milestone—commissioning—developers may claim 40 percent of the grant value for the number of connections beyond what they already claimed at the first milestone. The remaining 20 percent value of the grants will be disbursed after 3 months of satisfactory service as envisioned originally.

THE CBN'S SOLAR CONNECTION INTERVENTION FACILITY

The CBN established a N140 billion (US$339 million) concessional credit line to support the expansion of electricity access to 5 million households (about 25 million people) through solar home systems or a mini grid connection. This initiative formed part of the Nigeria Economic Sustainability Plan launched by the Nigerian federal government to support economic recovery in response to COVID-19. The Solar Connection Intervention Facility aims to advance the government's efforts to provide affordable electricity to underserved rural communities through long-term, low-interest lending to manufacturers and assemblers of solar components (and other such upstream stakeholders) and to downstream retailers (such as mini grid developers) that have qualified to participate in the NEP. The facility targets companies involved in mini grid project development activities, including site identification and assessment, design, planning, customer acquisition, engineering, procurement, and mini grid construction.

The program seeks to increase local content. For this reason, eligibility for concessional loans through this facility is restricted to Nigerian-owned entities or consortia with at least 70 percent local ownership. It aims to create 250,000 new jobs in the energy sector. Accordingly, eligible companies must have a detailed vocational and technical training plan for employing local people—a commitment they must demonstrate. Mini grid projects with 100 percent imported solar photovoltaic components and balance of system with neither proof of local content nor a credible plan for its incorporation in the near term will not be considered.

To be eligible for loans from this facility, developers must be qualified to participate in the NEP and have satisfied its minimum technical and financial requirements. Interconnected mini grids were not eligible for NEP grants until the REA rules were changed in October 2021. These mini grids are now eligible to apply for loans from the CBN's facility.

TABLE F.1 Terms of working capital and term loans available through the Central Bank of Nigeria's Solar Connection Intervention Facility

FEATURE	WORKING CAPITAL LOAN	TERM LOAN
Maximum loan amount	Up to N500 million	Up to 70 percent of project cost
Tenor	Up to 3 years	Up to 7 years
Interest rate (annual percent)	10	10
Moratorium	Not applicable	Up to 2 years

Source: CBN 2020.
Note: N = Nigerian naira.

Upstream component manufacturers and assemblers access low-cost debt from the facility through participating financial institutions (that is, commercial banks licensed by the CBN). Downstream distributors and developers can access these funds as part of the Nigeria Economic Sustainability Plan.

The REA and the fund administrator, Meristem, will conduct technical and commercial due diligence.[6] Developers must provide a sufficient guarantee apart from ringfencing revenues through a revenue pledge account mechanism enabled by cash sweeps from assigned bank accounts.

Two types of loans are available to mini grid developers: working capital loans (based on average 3-year adjusted projected cash flows) and term loans (for equipment, civil works, and other purposes). The loanable amount depends on a company's actual and adjusted projected cash flows. The gross monthly repayment to the CBN (the sum of principal and interest payments) may not exceed 20 percent of the company's monthly revenue. Table F.1 lists the terms offered for each type of loan.

Applications for funding from the CBN facility are considered on the basis of successful completion of the qualification process for the NEP. Beyond the NEP's requirements to establish the technical and financial capacity of a developer and verify each project's compliance with the minimum technical standards and all applicable laws and regulations, the CBN has implemented additional conditions to ensure that projects consider it their highest priority to repay loans from the Solar Connection Intervention Facility from their revenues. These conditions include the following:

- Disclose all revenue accounts with banks and other financial institutions to the CBN.
- Disclose all third-party revenue collection agents to the CBN (and appoint only CBN-licensed entities as revenue collection agents).
- Appoint a deposit money bank to act as its principal collection bank.
- Arrange to ensure that all revenues collected in a month are swept to a single account with the principal collection bank.
- Allow the CBN-appointed fund administrator to monitor all revenue accounts.
- Allow the CBN to have the first claim on payments due from the revenue accounts.
- Allow the CBN to restrict withdrawals from all revenue accounts for a certain number of days until the monthly loan repayment to the CBN is made.

AFD'S SUNREF CREDIT LINE

The SUNREF project of the AFD supports innovative green financing in more than 30 countries through dedicated credit lines for local financial institutions.

SUNREF Nigeria provides a €60 million credit line to two local partner banks (the United Bank for Africa and Access Bank) as well as €9.5 million for grants to increase the appeal of green investments. Borrowers can finance up to 100 percent of the investment cost of eligible projects on attractive terms (concessional interest rates, long tenors, grace period); the loans can be in either US dollars or naira. They can be used solely to finance equipment and hardware costs; fund engineering design; hedge against risks; pay legal fees; support development; finance transaction and bid costs; fund installation services and works; finance insurance, metering, and monitoring costs; purchase an initial set of spare parts; and commission the mini grids.

Both energy-efficiency and renewable energy projects may be considered for SUNREF funding. Eligible renewable energy projects include captive renewable energy–generation projects, grid-connected renewable energy, and off-grid renewable energy. Mini grids using solar or wind are eligible; interconnected mini grids clearly satisfy the eligibility criteria. The program will not consider extensions of existing projects and targets. It prioritizes projects with the following attributes:

- Projects that would not be financed under normal market conditions
- Projects with a strong positive social impact
- Solar and biomass/biogas projects
- Small projects that are harder to finance.

SUNREF Nigeria offers technical assistance, implemented by Winrock International, to project developers and support to partner banks in appraising eligible green projects.

All projects seeking loans from Access Bank and the United Bank of Africa must meet their standard lending criteria in terms of creditworthiness and compliance with national legislation. SUNREF Nigeria also has certain additional conditions and features:

- Maximum loan value: US$10 million or equivalent per project.
- Minimum internal rate of return: 10 percent, calculated over a project life of 15 years.
- Minimum loan maturity: 5 years.
- Interest rates: Varies depending on the borrower but may not exceed the monthly published CBN prime lending rate minus 3 percent on naira-denominated loans or the subsidized interest rate paid by the partner banks to AFD plus 4 percent on dollar-denominated loans.
- Grants: Project sponsors may receive a grant of 5–20 percent of the loan amount upon successful completion of a project. This grant is not automatic and must be negotiated with the partner banks.

NOTES

1. The NEP was restructured in August 2020 to add a COVID-19 response subcomponent, which entailed a reallocation of funds from existing activities.
2. The 2016 Nigerian mini grid regulations define an unserved area as "an area within a Distribution Licensee's Network without an existing distribution system" (NERC 2016, section 3). The regulations define an underserved area as "an area that is already connected to the main grid through an existing main grid–connected distribution company (Disco) but the Disco's service is poor."

3. The REA grant process is described in detail in REA (2021).
4. To avoid delays, the grant application process was designed to operate in parallel with the Nigerian Electricity Regulatory Commission regulatory process (issuance of permits and approval of requested tariffs). The REA accepts and reviews grant applications from mini grid developers if they show that they have applied for the regulatory commission and other required government approvals. However, it disburses grant monies only when a developer shows that it has all necessary approvals from federal, state, and local government entities.
5. Odyssey Energy Solutions (www.odysseyenergysolutions.com) is an online investment and asset-management platform developed to facilitate large-scale capital deployment. The Odyssey platform manages data across the life cycle of distributed energy portfolios and helps to streamline project development, financing, and operations.
6. For more information on the process, visit REA, "Solar Power Naija," https://rea.gov.ng/solar-power-naija/.

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APPENDIX G

The Levelized Cost of Energy Storage in a Mini Grid

THE COST OF CYCLING A KILOWATT-HOUR INTO AND OUT OF A MINI GRID BATTERY

The levelized cost of energy storage (LCOS) is given by the following equation (Mayr 2016).[1]

$$LCOS = \frac{CAPEX}{\#cycles * DOD * C_{\text{rated}} * \sum_{n=1}^{N} \frac{(1 - DEG * n)}{(1+r)^n}}$$
$$+ \frac{O\&M * \sum_{n=1}^{N} \frac{1}{(1+r)^n}}{\#cycles * DOD * C_{\text{rated}} * \sum_{n=1}^{N} \frac{(1 - DEG * n)}{(1+r)^n}}$$
$$- \frac{\frac{V_{\text{residual}}}{(1+r)^{N+1}}}{\#cycles * DOD * C_{\text{rated}} * \sum_{n=1}^{N} \frac{(1 - DEG * n)}{(1+r)^n}}$$
$$+ \frac{P_{\text{elec-in}}}{\eta(\text{DOD})}$$

The first line of the equation addresses storage costs associated with capital expenditure (CAPEX), the second covers operation and maintenance (O&M) costs, the third reflects the residual value after the project's lifetime, and the fourth addresses the cost of the energy used to charge the battery, including the cost of electricity lost as a result of the battery's inefficiency (more electricity must be supplied to the battery when charging than comes out when discharging).

Table G.1 shows the computation of candidate values for the variables of the LCOS equation for lithium-ion (Li-ion) and lead-acid batteries. Key variables are the initial cost (CAPEX), the number of cycles before failure, the permissible depth of discharge, and the batteries' round-trip efficiency.

The LCOS formula includes the discount rate (set at the weighted-average cost of capital) and assumes a linear degradation of battery capacity over its lifetime. Cost assumptions are based on the financial cost averages observed in Nigeria

TABLE G.1 Variables used to compute the levelized cost of energy storage

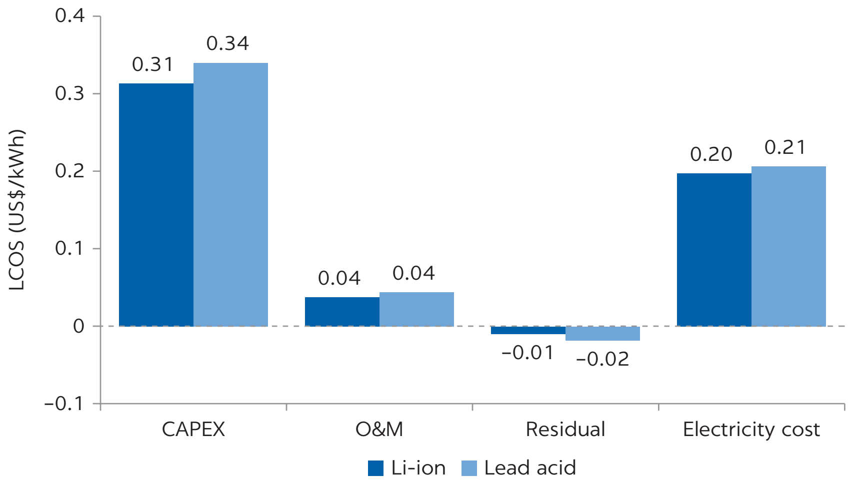
VARIABLE	UNIT	DESCRIPTION	INDICATIVE VALUE	LI-ION BATTERY (LIFEPO4)	LEAD-ACID BATTERY (OPzV)
CAPEX	US$	Up-front capital cost, including for a battery inverter and installation	Li-ion battery: US$414/kWh + US$65/kWh for an inverter Lead-acid: US$217/kWh + US$65/kWh for an inverter	479	282
No. of cycles	Cycles per year	Battery charge/discharge cycles per year	Assumed one cycle per day = 365 days per year	365	
DOD	Percent	Depth of discharge	Li-ion batteries can be more deeply discharged than lead-acid batteries	80	70
DEG	Percent per year	Portion of capacity degraded per year	Degrades to 80 percent capacity by end of project life	2	4
N	Years	Project lifetime	Li-ion: 10 years at 365 cycles (about 3,650 cycles to 80 percent DOD) Lead-acid: 5 years (about 1,825 cycles to 70 percent DOD)	10	5
r	Percent	Discount rate (weighted average cost of capital)	Assumes 70 percent debt at 10 percent interest and 30 percent equity with a 15 percent expected return on equity	11.5	
O&M	US$ per year	Operation and maintenance costs	Li-ion: About 2 percent of CAPEX Lead-acid: About 3 percent of CAPEX	10	10
$V_{residual}$	US$	Residual value of equipment at the end of the project's lifetime	Estimated at 10 percent value of CAPEX	48	28
$P_{elec\text{-}in}$	US$/kWh	Charging electricity tariff	Representing a typical tariff for bulk electricity from a Disco or the levelized cost of electricity from a solar array	0.16	0.16
$\eta_{(DOD)}$	Percent	Total charge-discharge efficiency, comprising the product of battery efficiency and the efficiency of the inverter in each direction	Battery inverter efficiency 95 percent in each direction + battery round-trip efficiency: • Li-ion: 90 percent • Lead-acid: 85 percent	81	78
LCOS	US$/kWh	Levelized cost of storage	The cost per kWh of electricity that has been stored in a battery	0.538	0.572

Source: ESMAP 2022.
Note: CAPEX = capital expenditure; DEG = portion of capacity degraded per year; Disco = distribution company; DOD = depth of discharge; kWh = kilowatt hour; Li-ion = lithium-ion; LiFePO4 = lithium iron phosphate; O&M = operation and maintenance; OPzV = Ortsfest PanZerplatte Verschlossen (with *Orsfest* meaning stationary, *PanZerplatte* meaning tubular plate, and *Verschlossen* meaning closed).

from a survey of 150 projects with Li-ion batteries and 50 projects with lead-acid batteries.[2] In Nigeria, the average cost was US$414 per kilowatt-hour (kWh) for Li-ion batteries and US$217/kWh for lead-acid batteries. Both battery types had an associated inverter cost of about US$65 per kWh of storage. The technical assumptions for Li-ion batteries are based on the default values for generic Li-ion batteries in the Hybrid Optimization of Multiple Electric Renewables (HOMER Pro) optimization software. The technical assumptions for lead-acid batteries are based on the HOMER Pro values for OPzS batteries, which are similar to the batteries used in Nigeria's Mokoloki project. The cost of electricity (US$0.16/kWh) is based on lower-end tariffs charged to the Toto and Wuse projects by the Abuja Electricity Distribution Company. The levelized cost of electricity (LCOE) to

FIGURE G.1

Cost components of Li-ion and lead-acid batteries



Source: Original figure created for this publication.
Note: CAPEX = capital expenditure; kWh = kilowatt hour; LCOS = levelized cost of energy storage; Li-ion = lithium-ion; O&M = operation and maintenance.

charge batteries is somewhat lower (about US$0.10/kWh) if electricity is available for charging from the mini grid's own solar panels. In this case, the LCOS is US$0.46/kWh for Li-ion and US$0.49/kWh for lead-acid batteries.

Although the cost per nameplate capacity for lead-acid batteries (US$217/kWh) is lower than that for Li-ion batteries (US$414/kWh), the superior efficiency, cycle life, and permissible routine depth of discharge of the latter result in a lower LCOE (refer to figure G.1).

The results depend on assumptions. If the discount rate is 18.5 percent, for example, the two battery types have the same financial LCOS. Higher discount rates favor lead-acid batteries, and lower discount rates favor Li-ion batteries. Product literature from the Chinese Li-ion battery manufacturer BYD Company Limited claims a lifetime of 6,000 cycles to 100 percent depth of discharge for its batteries, which would lead to an LCOS of US$0.516, with all other assumptions held constant.[3] (Readers interested in the implications of testing their own assumptions may do so using the spreadsheet available at http://tiny.cc/LCOS.)

The cost estimates in this appendix are comparable to those cited in Lazard's 2021 LCOS study, which finds that a residential photovoltaic + storage project with 25 kWh of storage and 6 kW of power output has an LCOS of US$0.545–US$0.785/kWh.

NOTES

1. The authors are grateful to Prof. Nathan Williams (Rochester Institute of Technology) for insightful comments on an earlier version of this appendix.
2. Financial costs include taxes and duties; economic cost does not. If economic costs are used, the LCOS is USUS$0.47/kWh for Li-ion and USUS$0.50/kWh for lead-acid batteries.
3. For more information on BYD, visit https://en.byd.com/energy.

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APPENDIX H

Tools for Mitigating Regulatory Risk

OVERVIEW

Regulatory risk can be mitigated via two World Bank Group mechanisms: (1) partial risk guarantees issued by the World Bank Guarantees group and (2) one or more of the political risk insurance products issued by the Multilateral Investment Guarantee Agency (MIGA).

PARTIAL RISK GUARANTEES

The World Bank Guarantees Program has provided partial risk guarantees for regulatory risk in the electricity sector on at least two occasions. The first was the 2004 privatization (that is, full asset sale) of two government-owned distribution enterprises in Romania. The second was the 2005 long-term lease of Uganda's government-owned distribution systems to UMEME (a private company). In both instances, partial risk guarantees were developed to guarantee compliance with fairly detailed, prespecified tariff-setting systems that would apply to the retail tariffs charged by the new private distribution operators.

On both occasions, the national governments signed a contract that included a regulatory tariff-setting formula as a provision. In effect, the governments provided sovereign guarantees that the newly created regulator would comply with the terms of the tariff-setting formula. As part of the partial risk guarantees, the World Bank agreed to promptly compensate private operators for revenue shortfalls resulting from the government regulators' failure to implement the prespecified tariff-setting formula.

Both national governments agreed to provide counter-guarantees (sometimes referred to as counter-indemnities) to the World Bank—promises to reimburse the World Bank for any payments made by it to private companies under the partial risk guarantees for noncompliance by national regulators under the contract terms. For poorer countries in the World Bank's International Development Association, the counter-indemnity would, until paid, count as a contingent liability that would reduce the amount of money that could be provided under a country's periodic International Development Association allocation.

The requirement that national governments provide counter-guarantees to the World Bank created formal financial commitments for these governments. The counter-guarantees strongly incentivized both regulators and governments to adhere to the terms of the regulatory agreement.

Another incentive to both governments was the need to avoid being perceived as not honoring commitments, especially because they were both seeking assistance from the World Bank and other donors for projects in other sectors.

POLITICAL RISK INSURANCE PRODUCTS

MIGA offers four political risk insurance products to support foreign direct investment in developing countries:

1. Transfer restriction and currency inconvertibility insurance insures against the inability to convert or transfer dividends or loan payments because of foreign exchange restrictions.
2. War and civil disturbance insurance insures against destruction or interruption of business due to political violence.
3. Expropriation insurance insures against any action or inaction by a government or government entity that may reduce or eliminate ownership of, control over, or rights to the insured instruments. It could include creeping expropriation (a series of acts that, over time, have an expropriating effect), regulatory actions, and changes in law.
4. Breach-of-contract insurance protects against the failure of a government or a state-owned enterprise to honor contractual obligations and arbitration agreements.

MIGA can provide insurance coverage for 95 percent of debt and 90 percent of equity for up to 15 years, with an increase to 20 years under certain circumstances. Unlike the guarantees issued by the World Bank Guarantees group, MIGA's insurance products do not require a counter-guarantee or counter-indemnity from host governments if MIGA pays out against a claim. It may not be feasible for MIGA to offer breach-of-contract insurance in a particular country, but a developer could apply for its other three products.

MIGA has long been providing one or more of these political risk insurance products for large, main grid–connected generating plants developed, owned, and operated by private investors. These projects, generally undertaken by independent power producers, typically require financing of many millions of dollars. MIGA's expropriation and breach-of-contract insurance products have been used, individually or in a package, to mitigate regulatory risks for many such projects. For independent power producers, power purchase agreements, concession agreements, and other arrangements typically include specific tariff and regulatory stability clauses, which can be backstopped by MIGA's breach-of-contract product.

It is more complicated to implement MIGA's expropriation product, which excludes "bona fide, nondiscriminatory measures of general applicability" (MIGA 2018, 7). For mini grids, this clause presumably means that, if the national electricity regulator decides to unilaterally lower the retail tariffs for all mini grids of both domestic and foreign-owned companies by 50 percent, this action would not be considered expropriation directed at foreign investors, because of its general applicability.

To avoid ambiguity about whether expropriation insurance covers a given regulatory act, one potential solution is to enshrine it in a contractual obligation for the government that is separate from any tariff decision by the regulator. For example, breach-of-contract insurance could cover a situation in which the ministry of finance enters into a separate contract with mini grid developers to reimburse them for any shortfalls resulting from the regulator's nonadherence to its previously approved tariff-setting formula. In effect, the ministry of finance or some other government ministry would be guaranteeing that the national electricity regulator will implement its tariff and other regulatory decisions as written. This arrangement requires the willingness of some other part of the government to backstop the regulator's decisions. It also requires that the regulator's tariff-setting formula for mini grids is written in sufficient detail so that it is clear when it has not been followed. In the absence of a functioning national electricity regulator, the tariff-setting system could be embedded into an agreement signed by the ministry of finance or some other authorized government ministry.

IMPLEMENTING REGULATORY RISK–MITIGATION PRODUCTS

Any regulatory risk–mitigation product will need to address at least four key implementation questions, which are discussed next.

Is there a contractual agreement that covers the mini grid regulatory system, and is the national or state government a signatory to that contract?

A breach-of-contract instrument for a mini grid regulatory system typically requires a contractual agreement that specifies the terms and conditions for a mini grid's retail tariff–setting system and an eligible government entity that is a signatory to the contract. The backup contractual agreement must be with an eligible government counterparty that has the authority to bind the government in an agreement. The government obligations should be considered commercial (not sovereign or government) obligations, and the agreement should also include a dispute-resolution mechanism as well as provisions describing the consequences of a breach.

Democratic Republic of Congo

The national government of the Democratic Republic of Congo adopted a top-down zonal concession approach as its preferred initial option. In November 2020, after an international competitive tendering process, the government awarded three 22-year concessions to a consortium of private sector companies (AEE Power, Eranove, and Gridworks) to develop large separate mini grid systems in the provincial capitals of Bumba, Gemena, and Isiro, in the country's northern region. The three projects are expected to require at least US$100 million in investment and serve more than 22,000 households and businesses in the first 5 years.

The Democratic Republic of Congo does not have a functioning electricity regulator, so it was proposed that the Ministry of Hydraulic Resources and Electricity be the government signatory to the concessions. Under the Scaling Mini Grids program of the International Finance Corporation (IFC), the government agreed to enter into concession agreements that include a prespecified tariff-setting formula as a key component—a form of regulation by contract. It has been proposed that the country's zonal mini grid concessions be supported by MIGA-issued breach-of-contract instruments.

India and Nigeria

Contracts like the ones described in the previous paragraphs do not exist in India or Nigeria for bottom-up privately owned and operated mini grids. In India, mini grids are deregulated; mini grids located in designated rural areas require neither a license nor approval of their tariffs by a state electricity regulatory entity or the national electricity regulatory entity (and thus no contract is in place to be breached). Nigeria's national electricity regulatory entity (the Nigerian Electricity Regulatory Commission [NERC]) reviews and approves the proposed retail tariffs of privately owned and operated mini grids, but it is not a signatory to a contract with developers.

A different institutional arrangement might make it possible to offer regulatory partial risk guarantees or political risk insurance coverage in Nigeria. Nigeria divides grant and regulatory functions between two national government entities. The Rural Electrification Agency (REA) provides capital cost grants (described in appendix C), and NERC reviews and approves proposed retail tariffs of mini grids. If both of these functions were assigned to the REA, it would be a signatory to a contract that covers both grants and tariff setting. In this case, the contracts could conceivably be backed up by a risk-mitigation product.

Such an instrument would reduce regulatory risk for developers, although there is a potential cost to transferring mini grid tariff-setting responsibilities to the REA. It would divide the regulation of the electricity sector between two government entities: the REA would be the mini grid regulator, and NERC would continue as the main grid regulator. Division of regulatory functions always carries a risk of a conflict between the actions and decisions of the different entities. This issue is especially relevant in the case of an interconnected mini grid, which would have to interact both commercially and operationally in multiple ways with distribution companies (Discos) and other main grid–connected entities.

Two other impediments exist in addition to the risk of dividing regulatory functions between two government entities. First, the REA is not a credible counterparty unless it has a budget that lets it commit to fund future possible tariff shortfalls in addition to the up-front grants it provides to mini grids. Second, changes to the laws that established NERC and the REA would be needed to implement this new system. Given these difficulties, this option does not appear viable for Nigeria.

How much will annual premiums be?

Most mini grid projects operate on the edge of financial viability. Developers of undergrid mini grids will understandably be highly sensitive to the cost of the premiums for risk-mitigation instruments like partial risk guarantees or political risk instruments, which could raise mini grids' retail tariffs (which are probably already two to four times higher than local Discos' grid tariffs) even higher.

Concessional funding is available to offset or reduce the costs caused by premiums, although developers will be asked two questions: How much would the premiums cost? And by how much would they raise the tariff the mini grid operator needs to charge? The developer's financing costs may fall if the existence of a partial risk guarantee or political risk insurance leads to a larger pool of competing organizations that are willing to provide debt financing. The key question, therefore, is whether the reduction in debt financing costs will exceed the added cost caused by premiums.

Which elements of the mini grid regulatory system will be covered?

Regulators' decisions affect the revenues and costs of interconnected mini grids in numerous ways, including a retail tariff-setting formula, the permitted charges for leasing Discos' existing facilities, the price paid by a mini grid for power purchased from a Disco, the price received by the mini grid for electricity sold to the Disco, and the compensation received by the mini grid if a Disco or the national utility takes over its assets. Regulatory risk instruments should cover all these cost and revenue components if they are affected by regulatory decisions.

What is the cost of applying for a regulatory risk–mitigation instrument?

The financial costs of applying for a regulatory risk–mitigation instrument are relatively low, although a potentially significant time commitment exists.

The application costs and processing fees for MIGA's political risk insurance products are not insignificant (the application fee is approximately US$5,000–US$10,000, in addition to processing fees of about US$5,000–US$50,000, depending on a transaction's particulars). Mini grids can be grouped into portfolios that can share a single application fee and processing fee.

The heavy time commitment associated with applying for a regulatory risk–mitigation instrument could be managed through better coordination among equity, debt, and guarantee providers to harmonize due diligence efforts and external reports. For example, the due diligence process could be coordinated through a World Bank grant program or a multilateral donor initiative, such as the Universal Electrification Facility.

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APPENDIX I

Cost-Sensitivity Analysis for Interconnected Mini Grids

THE IMPACTS OF LOAD VARIATIONS, BULK POWER PURCHASES, AND CAPITAL GRANTS

What is the cost of reliable electricity from a grid-interconnected mini grid? How does it vary with the timing and duration of the load? How does the availability of wholesale or bulk electricity that can be purchased from a distribution company (Disco) affect the cost? To what extent can capital grants help lower the cost of energy? Chapter 4 and this appendix answer these questions using data from six proposed grid-connected mini grids in Nigeria.

METHODOLOGY

The Nigerian Energy Support Programme (NESP) has developed a data set of the characteristics of six proposed interconnected mini grids to be supported by in-kind equipment grants from NESP under the ongoing Interconnected Mini-grid Acceleration Scheme (IMAS).[1]

The technical and financial consultant for the IMAS program (Integration Consulting Energy and Environment GmbH) examined the cost implications of the questions posed in the opening paragraph. The firm calculated the levelized cost of electricity (LCOE) based on the average characteristics of the six proposed interconnected mini grid projects and how they would be affected by changes in the load factor, external grants, and the availability of electricity purchased from the local Disco, as described in chapter 4. LCOE values are determined by the capital expenditure (CAPEX) needed to build a mini grid and the operating expenditure (OPEX) needed to keep it running. The LCOE combines these costs into a single cost per kilowatt-hour to deliver electricity to mini grid customers over the mini grid's lifetime. This LCOE value is equivalent to the minimum average tariff a developer needs to charge to make a project commercially viable. Box I.1 describes an LCOE calculation based on surveys of over 400 isolated mini grids.

BOX I.1

Cost analysis of isolated mini grids in ESMAP's *Mini Grids for Half a Billion People*

Chapter 1 of the Energy Sector Management Assistance Program (ESMAP) publication *Mini Grids for Half a Billion People* (2022) provides a thorough cost analysis based on detailed component-level cost surveys of over 400 isolated (non-grid-connected) mini grids commissioned (or contracted to be commissioned) between 2012 and 2021. The survey responses include detailed data down to the component level (solar panels, batteries, inverters and energy-management systems, distribution networks, land, logistics, and transportation).

Using detailed cost information collected in the surveys, ESMAP calculated levelized costs of electricity (LCOEs) for optimized mini grids based on capital expenditure and operating expenditure in Ethiopia, Myanmar, and Nigeria, as well as LCOEs for global average and "best-in-class" mini grids. ESMAP calculated LCOEs for a variety of load curves, including those found in typical rural villages with largely residential loads, communities with small industries with significant daytime productive-use loads, and aspirational "sun-following" load curves that concentrate most load during daylight hours. Best-in-class mini grids have financial LCOEs of US$0.244–US$0.403/kilowatt-hour (kWh), depending on the shape of the load curve. The economic LCOE is US$0.229–$0.377/kWh.

ESMAP's report also charts the precipitous cost decline for key components (solar panels, batteries, inverters) in recent years and makes projections for component costs for mini grids to be commissioned in 2030. It projects that the financial LCOE for best-in-class mini grids will drop to US$0.308/kWh (US$0.292/kWh for the economic LCOE) for typical rural residential community loads, and to US$0.217/kWh (US$0.204/kWh for the economic LCOE) for mini grids with substantial daytime productive use.

To maintain the confidentiality of individual projects, a single hypothetical project was created using average component unit costs from the first six mini grids being supported under the IMAS program. This project was optimized for a load profile equal to the average load profile of these first six IMAS mini grids. All sensitivity calculations were made using the mini grid simulation and optimization software, Hybrid Optimization of Multiple Electric Renewables (HOMER Pro).

Technical and commercial characteristics of the hypothetical interconnected mini grid

Appendix J describes the technical and commercial characteristics of the hypothetical interconnected mini grid.

Load factor

A mini grid's load factor gauges the full use of the generation. The load factor is computed by dividing the average load by the peak load over a given period. A year appears to be the appropriate time period to use in determining the load factor, because it accommodates day-to-day load variation, which can occur over hundreds of days, and load differences associated with seasonal change.

In general, a high load factor improves mini grids' economics. For solar mini grids, a high load factor is especially beneficial when it is achieved by increasing the daytime load. When electricity is consumed as it is being produced, during sunlight hours, it does not need to be cycled into and out of battery storage, which wears down the batteries, or produced by diesel generators. Using a large portion of electricity during sunlight hours reduces the portion of the LCOE associated with storage.

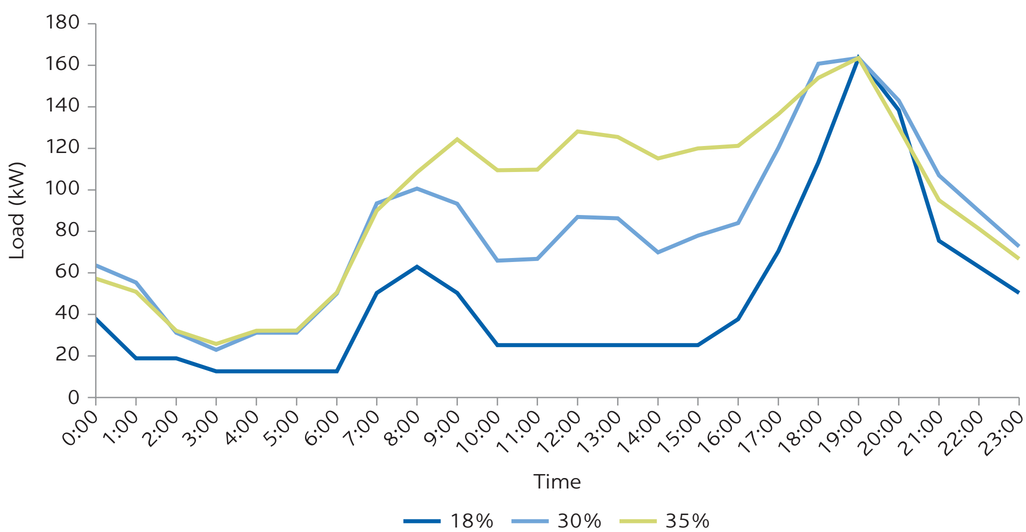
Mini grids can increase the load factor by offering customers discounts if they curtail their load intermittently. The smart meter technology employed by Husk Power Systems (see case study 5 in chapter 2) allows customer-level curtailment during periods of electricity scarcity and performs conventional mini grid smart meter functions, such as measuring electricity for revenue collection, collecting data on customers' voltage levels, sending low-balance alerts to customers, and allowing top-up via mobile money platforms (Mugyenyi and others 2021).

Figure I.1 shows three load curves. Increases in daytime load are typically achieved by encouraging customers to use productive-use machines during the day (examples include machines for agricultural processing, water pumps, and refrigerators and freezers for preserving crops or fish). The lowest curve represents a typical rural residential load, with a high peak in the evening and early night hours and much smaller morning and noon peaks. Usage in the middle of the night is low. This curve has a load factor of 18 percent annually.[2] The middle curve represents a village with no increase in the evening peak and moderate daytime productive use, leading to a load factor of 30 percent. The highest curve adds yet more daytime load, achieving a load factor of 35 percent.

Sensitivity analysis using HOMER Pro for the three load curves indicates that the LCOE/kilowatt-hour (kWh) is US$0.39, US$0.37, and US$0.35 for load factors of 18 percent, 30 percent, and 35 percent, respectively (refer to figure I.2).

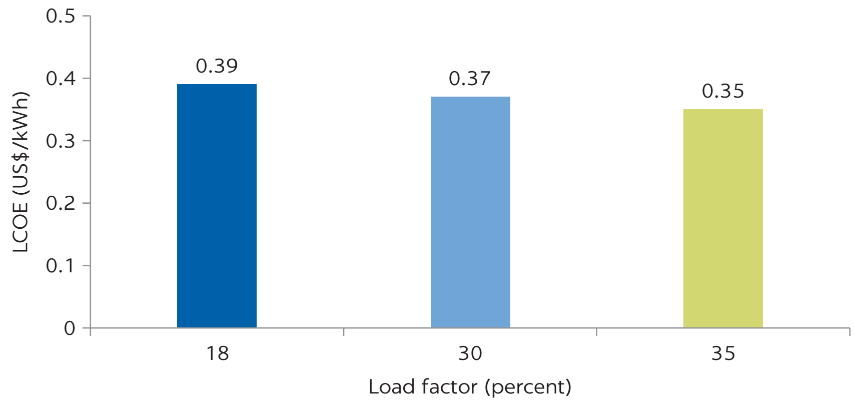
FIGURE I.1

Electricity consumption profiles at load factors of 18 percent, 30 percent, and 35 percent



Source: Integration Consulting Energy and Environment GmbH.
Note: kW = kilowatt.

FIGURE I.2
Effect of load factor on the levelized cost of electricity



Source: Integration Consulting Energy and Environment GmbH.
Note: kWh = kilowatt-hour; LCOE = levelized cost of electricity.

Increasing the load factor has great benefits when it occurs during the daytime (sunlight hours). This difference is presented in the sensitivity analysis in figure I.3, which shows two load curves, both with a load factor of 35 percent. The dark blue curve (panel a) shows significantly more daytime load; the light blue curve shows significantly more nighttime load. A HOMER Pro analysis of the two cases yields a US$0.02/kWh increase in cost, from US$0.35/kWh (daytime 35 percent load) to US$0.37/kWh (nighttime 35 percent load).

PURCHASES FROM THE DISCO

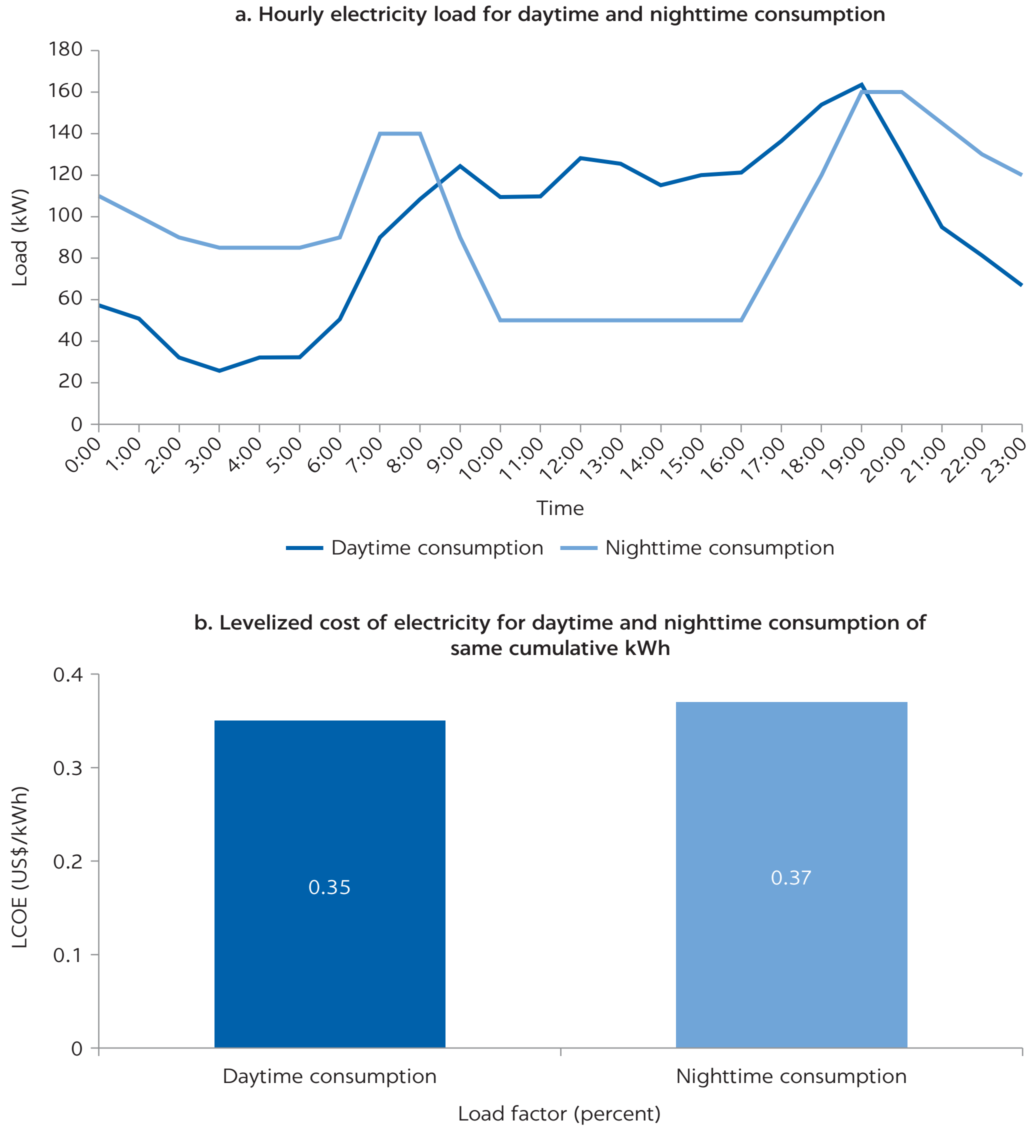
For a mini grid operator, purchasing electricity from a Disco can reduce both its OPEX and its CAPEX. In Nigeria, purchasing electricity from a local Disco costs less than generating it from an on-site diesel generator or withdrawing it from batteries. For the first six proposed IMAS interconnected mini grids, local Discos were expected to sell electricity to the mini grids at prices of US$0.11–US$0.17. It would cost a mini grid approximately US$0.50/kWh on average to source the same electricity from batteries or diesel generators. Given these numbers, an interconnected mini grid would always choose to draw electricity from a local Disco, unless the timing of the load permits direct production of sufficient electricity from the photovoltaic (PV) panels.

Purchasing electricity from a local Disco can also reduce (or at least further optimize) mini grids' initial CAPEX. The prospect of abundant sufficiently low-price electricity (even if intermittent) from a Disco should encourage mini grid developers to alter their system designs, relying less on solar PV (which requires more up-front investment) and more on power from the Disco when it is available. When electricity is not available from the Disco, mini grids can fall back on their diesel generators.

Optimization of system design would depend on when electricity is available from a Disco. Greater availability of Disco electricity during peak evening hours (which is unlikely, given Discos' commitment to their own retail customers) could lower investments in both PV panels and batteries. Increased availability in the middle of the night might drive increased investment in batteries to benefit from inexpensive nighttime charging. Such investment will be viable if

FIGURE I.3

Differences in levelized cost of electricity for daytime and nighttime consumption with 35 percent load factor



Source: Integration Consulting Energy and Environment GMbH.
Note: kWh = kilowatt-hour; LCOE = levelized cost of electricity.

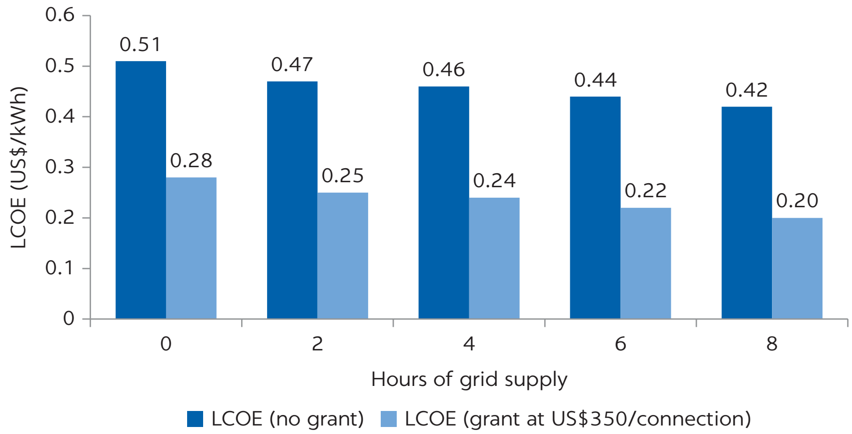
the Disco's wholesale purchase price, combined with the levelized cost of storage, is lower than the cost of generating electricity from a diesel generator.

Developers will have even stronger incentives to reduce expenditure on PV energy and batteries if Discos can firmly commit to delivering power during evening hours. PowerGen believes that local Discos' firm commitment to supplying electricity to the Toto mini grid over 6 hours in the evening will allow the mini grid to reduce its initial capital investments by 15–20 percent compared with a fully isolated mini grid.

Figure I.4 shows the effect of varying bulk purchase levels on the LCOE of the hypothetical IMAS mini grid with a connection to a Disco but no firm commitment in cases with and without a CAPEX grant of US$350 per connection. With no purchase from the Disco, the mini grid's LCOE will be US$0.51/kWh without

FIGURE I.4

Projected levelized cost of electricity with and without a grant for a mini grid that purchases nonfirm electricity from the local Disco



Source: Integration Consulting Energy and Environment GmbH.
Note: Diesel fuel is assumed to cost US$0.35/liter. Electricity is assumed to be sold by the Disco on an "as available" basis. The discount rate is set equal to a weighted-average cost of capital of 12.5 percent. Disco = distribution company; kWh = kilowatt-hour; LCOE = levelized cost of electricity.

a grant and US$0.28/kWh with one. Its LCOE drops by about US$0.04/kWh without a grant and about US$0.03/kWh with a grant if it purchases 2 hours of electricity a day from the Disco.

Increases in the hours of grid supply produce a relatively small decline in the LCOE (just 4 percent for a 2- to 4-hour increase in grid supply, for example). Two likely explanations for this relatively small decline in the LCOE are discussed further.

First, the cost of a liter of diesel fuel was low in Nigeria (the value used for the sensitivity calculations was US$0.35/liter).[3] In most other African countries, a liter of diesel fuel costs about US$1.00 or higher. Therefore, running a diesel generator for fewer hours generates lower savings in Nigeria than it would in countries where diesel costs more. However, with the government of Nigeria's decision on June 1, 2023, to stop subsidizing the price of diesel, mini grid operators will save even more if they can increase their purchases of Disco-supplied grid electricity.

Second, there is no CAPEX reduction for this hypothetical mini grid. Faced with grid supply uncertainty, mini grid developers made their sizing decisions assuming that the grid is never available. The cost of an incorrect guess about the availability of grid power could be greater than the benefit of a correct guess. Over time, local Discos may be willing and able to make firm bulk supply commitments to mini grids interconnected to Discos' systems, enabling optimized sizing of mini grids.

It is unlikely that a mini grid in Nigeria—whether interconnected or non-interconnected—will be able to achieve commercial viability while charging affordable tariffs without subsidies or grants. Nigeria's Rural Electrification Agency (REA) administers a World Bank–funded program that provides monetary grants of US$600 per connection. Originally, the program provided grants only to non-interconnected mini grids, but on October 15, 2021, the REA announced that it would also provide the grants to interconnected mini grids (refer to appendix F).[4]

Effect of capital equipment grants for proposed interconnected mini grids in Nigeria

Figure I.5 shows the effect of different grant levels on the LCOE. The data are averaged for the six IMAS projects.[5] The IMAS program provides a grant of about US$350 per connection for donor-supplied equipment for the proposed interconnected mini grids. At this grant level, the LCOE is about US$0.24 (N99)/kWh. An increase of the grant to US$400 per connection (about 14 percent increase) would cause a 14 percent decrease in the LCOE, to US$0.21 (N87)/kWh. Without any grant subsidy, the LCOE of the interconnected mini grid would need to jump to US$0.46 (N190)/kWh for the mini grid to be commercially viable.

Size of capital grants

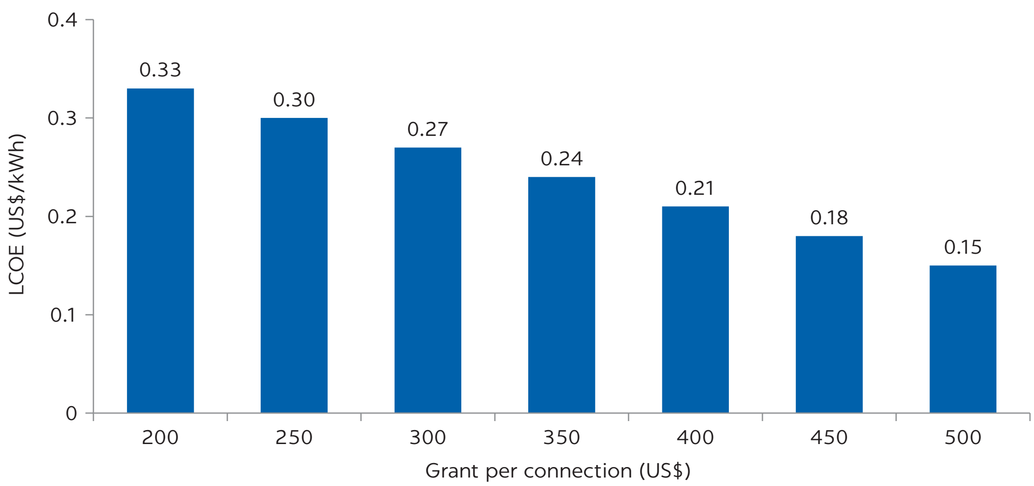
The CAPEX per customer differs between interconnected and isolated mini grids. Interconnected mini grids—at least those encountered in Nigeria—benefit from economies of scale, because they are considerably larger than most isolated mini grids.

Interconnected mini grids (at least those in the IMAS program) also have the benefit of being able to lease Disco poles and wires, reducing their initial capital investment. They may have to invest in rehabilitating and expanding the existing distribution grid, however. PowerGen expects to invest US$500,000 out of a US$2 million total CAPEX investment to repair and expand the existing Disco mini grid in Toto, for example, as described in the case study in chapter 2.

Developers of interconnected mini grids need to determine whether their project will be eligible for performance-based capital grants and if so how large the grants will be.[6] We believe that most projects will be eligible for grant funding. Like isolated mini grids, interconnected mini grids can bring improvements in electricity supply to households and businesses if they are commercially viable. The size

FIGURE I.5

Effect of grant per connection on levelized cost of electricity for average IMAS-supported mini grid



Source: Integration Consulting Energy and Environment GmbH.
Note: kWh = kilowatt-hour; IMAS = Interconnected Mini-grid Acceleration Scheme; LCOE = levelized cost of electricity.

of the grant is not clear. A data-driven answer would require comparison of the LCOE supplied by isolated and interconnected mini grids. Little information on LCOEs for interconnected mini grids is available.

The costs of an interconnected mini grid depend largely on the reliability with which it can purchase power from the local Disco, the price of that power, and the condition of the Disco's distribution grid. Power purchased from the Disco has the potential to lower a mini grid's CAPEX and OPEX, with the magnitude of the cost reduction depending on the amount of power received, the time of day it is supplied, the reliability of the power supply, and the price charged by the Disco. All of these factors differ widely across locations.

The investment costs for an interconnected mini grid will depend on the condition of the distribution grid and the size of the investment required to replace or refurbish it. Interconnected mini grids will also have additional CAPEX, for example, associated with the purchase of protective equipment and switchgear required for the interconnection itself (as discussed in chapter 5).

Better data are needed to understand the effects on CAPEX and OPEX before we can make a data-driven recommendation on an appropriate grant level for interconnected mini grids. A comparison of the costs in the Nigeria Electrification Project for isolated mini grids with the costs in the IMAS program for interconnected mini grids should provide some insights. Better cost and operating information should be available by 2024 or 2025. Once it is, the issue of the grant size can be revisited.

Bureaucratic slowness

It is not uncommon for mini grid developers to make off-the-record comments that go something like this:

> Sure, the regulatory and grant systems look fine in reports and conference presentations. But what is often ignored is how long it takes the regulator to make a decision on our permit application and the rural electrification agency to process grant disbursements. I am not saying that these government officials have bad intentions. These are good people, and I can see that they work hard. But these agencies are understaffed for the tasks they have been assigned. If they are already having difficulties processing 40 or 50 mini grid applications, delays are only going to get worse if the number of proposed projects scales up into the hundreds or thousands. And the sad reality is that developers can go bankrupt while waiting for the electricity regulator and the rural electrification agency to process permit applications and grant disbursements. When this happens, everyone—customers, the government, and the developer—loses.

Consider the case of the Nigerian REA's mini grid performance-based grant (PBG) program for solar and solar hybrid mini grids. The program currently specifies three grant-disbursement milestones. The first is the arrival of mini grid equipment (PV panels, inverters, batteries, and meters) at the mini grid site. Once documented, achievement of this milestone allows a developer to receive up to 40 percent of the total per-connection grant (currently US$600), depending on the number of meters that have been deployed on site.

The second milestone is commissioning, which requires the developer to demonstrate that the mini grid is in working condition, wires have been energized, and at least one customer has been connected. Verification of this milestone triggers an additional payment of up to 40 percent of the total per-connection grant, linked to the number of metered connections that can be verified on the Odyssey platform.[7]

The third milestone is tied to the verification of metered customers having received 3 months of electricity supply from the mini grid. This verification is based on metering data made available by the developer on the Odyssey platform.[8] Achievement of this milestone triggers the payment of the remaining grant amount on a rolling basis as connections are achieved. Appendix F offers a complementary explanation of these milestones.

Mini grid developers in Nigeria have experienced delays in REA's processing of their grant disbursement requests. Several reasons, including understaffing, COVID-19, and security concerns, hindered REA staff from making timely visits. In late 2021, several completed mini grids were physically ready to sell electricity but could not do so legally because they were still waiting for on-site commissioning inspections (Milestone 2) by REA staff. These delays displeased everyone: the developers, who are losing potential revenues; the REA, which cannot report an increase in the number of operating mini grids; and World Bank staff, who have to explain to their senior management why the level of grant disbursement has not achieved its targets.

Self-certification initiative

The REA recognized that its processes were creating bottlenecks that would likely worsen as the number of mini grid grant applications increased. Its staff proposed a novel solution, called the PBG Virtual Site Report, to accelerate the inspection process for grant disbursements. The report allows developers to self-certify the achievement of the first two milestones. The self-certification template allows developers to upload time-stamped and geo-referenced photos showing that the equipment is in place and construction is completed (Milestone 1) and that grids are producing electricity and meters are measuring individual customer's consumption (Milestone 2). The serial number of each customer's meter must be visible in the photos. The serial number can then be cross-checked against customer consumption data linked to specific meters. These data are automatically uploaded to the Odyssey reporting system.

The REA has taken several steps to reduce the likelihood of cheating. It requires companies to formally attest to the accuracy of the submitted information. It expects to conduct random audits at mini grid sites that received grant payments under this new system. The discovery that a mini grid company has submitted false or misleading information can result in the REA terminating the grant agreement and requiring the grantee to refund some or all of the grant previously disbursed.

NOTES

1. Appendixes C and J contain more information on the IMAS program. We thank NESP for allowing us access to its data set. We also benefited from in-depth discussions with INENSUS GmbH, another consulting firm hired by NESP to work on the IMAS program.
2. If the load factor is computed over the time of day, it would be a simple ratio of the average load for a given day and that day's peak load. Estimating the load factor on an annual basis introduces the complexity of daily load variation. HOMER Pro modeling addresses this issue by synthesizing a year's worth of data based on the daily load curve. To do so, our

analysis assumed HOMER's default values of a 10 percent random daily load variation and a 20 percent random hourly load variation. These random variations increase the peak load on some days, lowering the load factor, because the variations increase the maximum load but do not affect the average load. The daily load factors for the three load curves shown in this section are 30 percent, 50 percent, and 60 percent.

3. These calculations were made in 2020, when the price of diesel fuel was US$0.35/liter. In December 2021, the price was almost double that.
4. The Universal Electrification Fund, a new initiative of the United Nations Energy for All program, has proposed providing per-connection grants of US$400 or more to mini grid developers in Benin, Madagascar, and other countries where the program will operate. In Tanzania, the national REA has provided grants of US$500 per connection to several mini grid projects. Grants for rural electrification are the norm in most countries. A Duke University study of rural electrification through main grid expansion found that the average subsidy per customer in seven countries (Brazil, Chile, the Lao People's Democratic Republic, Peru, South Africa, Thailand, and Tunisia) ranged from US$1,050 to US$1,500 (Phillips, Plutshack, and Yeazel 2020).
5. In Africa, grants to private mini grid operators are usually limited to capital-cost grants, provided as equipment or money. In contrast, the subsidies given to government-owned electricity utilities take multiple forms, including government grants, subsidized loans from governments and donors, subsidized inputs from donors, transfers of public funds from the national treasury, and government loans that become grants when a utility is not able to pay back the government (refer to Foster and Rana 2020, chapter 8). Governments also give nonpublicized subsidies to privately owned Discos. In Nigeria, for example, it has been estimated that as much as 50 percent of the power purchase costs of the 11 privately owned Discos are paid for through federal government subsidies.
6. On October 15, 2021, Nigeria's REA announced that it would increase the size of its monetary grants from US$350 to US$600 per connection. It also declared that interconnected mini grids would be eligible for the full US$600 grant. Refer to appendix F for a description of these and other announced changes.
7. The Odyssey platform is an end-to-end tool for planning, financing, managing, and monitoring mini grid projects at scale. The REA is using this platform to implement its PBG program. Aside from the techno-economic analysis of mini grid projects, the PBG program uses the Odyssey platform to verify customer connection and electricity consumption for projects that include smart metering (phone and physical verification apply to mini grids without smart meters). Once customers are connected to a mini grid, their meters will need to be integrated with the Odyssey platform via a publicly available application programming interface. For verifying connections and receipt of electricity services by customers, the REA requires only some activity on the meters and not any minimum level of electricity consumption, which is not under the direct control of the mini grid operator.
8. To verify that electricity has been supplied for 3 months, the meters integrated with the Odyssey platform need only show that some electricity consumption has been recorded 3 months apart.

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APPENDIX J

Assumptions Underlying Cost Calculations in the Interconnected Mini-Grid Acceleration Scheme

KEY VALUES FOR CAPITAL AND OPERATIONAL EXPENSES

The cost calculations in chapter 4 would not have been possible without data on the Interconnected Mini-grid Acceleration Scheme (IMAS) mini grids collected by the Nigerian Energy Support Programme (NESP) and modeling by Integration Consulting Energy and Environment GmbH. Our colleagues at NESP have developed a very rich data set of the physical and commercial characteristics of six proposed interconnected mini grids that will be supported by in-kind equipment grants from IMAS (refer to appendix C). They generously gave us access to this data set and the assistance of Integration Consulting, the technical and financial consultant for the IMAS program.

To maintain the confidentiality of individual projects, we created a single hypothetical project using average component unit costs from the first six mini grids being supported under the IMAS program. This single hypothetical project was optimized for a load profile equal to the average load profile of these six mini grids. All sensitivity calculations were made using the mini grid simulation and optimization software, Hybrid Optimization of Multiple Electric Renewables (HOMER Pro).

Integration Consulting computed the financial levelized cost of electricity (LCOE) based on the average characteristics of the six proposed interconnected mini grid projects and the ways in which changes in the load factor, external grants, and the availability of electricity purchased from the local distribution company (Disco) would affect the LCOE.[1]

Table J.1 shows the key market, technical, and financial parameters of the hypothetical average interconnected mini grid. Several points are worth noting:

- As of mid-December 2023, Nayo Tropical Technology was expected to finalize construction of one mini grid—at Lambata—by January 2024. Darway has started construction of one of its four sites. No project is yet operational. There is no certainty that the projected numbers of the projects will prove accurate.
- The projects will receive significant grants to cover their capital expenditures: on average, about 60–70 percent of the overall capital costs will be covered by in-kind grants from the IMAS program.

TABLE J.1 Average values for the key parameters of a hypothetical interconnected mini grid based on the first six proposed IMAS projects

ITEM	VALUE
Market parameters	
Number of connections	2,280
Number of customers served	12,000
Demand (MWh/year)	550
Technical parameters	
PV capacity (kWp)	395
Battery capacity (kWh)	320
Diesel genset(s) (kW)	70 + 50
Diesel fuel price (US$/liter)	1.80[a]
Capital costs of equipment	
Battery cost (US$/kWh)	350
PV cost (US$/kWp)	420
Diesel generator cost (US$/kW)	200
Converter cost (US$/kW)	530
Wholesale tariff for purchase from the Disco (US$/kWh)	
Low	0.13
High	0.50
Financial parameters	
Capital expenditure (US$, thousands)	990
Grant per connection (US$)	350–400 subject to cap
Grant ceiling cap per project (US$, thousands)	695
Equity (US$, thousands)	148
Debt (US$, thousands)	190
Discount rate (percent)	12.5

Source: Integration Consulting Energy and Environment GmbH.
Note: IMAS = Interconnected Mini-grid Acceleration Scheme; kW = kilowatt; kWh = kilowatt-hour; kWp = kilowatt-peak; MWh = megawatt-hour; PV = photovoltaic.
a. GlobalPetrolPrices.com, "Nigeria Diesel Prices, 31-Oct-2022" (https://www.globalpetrolprices.com/Nigeria/diesel_prices/), accessed November 6, 2022.

- The overall projected capital costs of the average project will be close to US$1 million. By contrast, the capital costs of isolated, non-interconnected mini grids in Sub-Saharan Africa are reported to be in the range of US$0.5 million to US$1.0 million (ESMAP 2022).
- The average project will have 2,280 connections—many more than reported for the average existing isolated, non-interconnected mini grid in Africa. IMAS is offering an in-kind grant of about US$350–US$400 per connection, with a cap of US$695,000 per mini grid. For the analysis, the discount rate was set at 12.5 percent with an annual inflation rate of 1 percent.[2]

NOTES

1. A financial LCOE is calculated from the perspective of the developer. It includes all costs reported by developers in constructing and operating a mini grid, as well as the cost-increasing effects of duties and taxes and the cost-reducing effects of grants. An economic LCOE removes taxes, duties, and grants from the calculation because they constitute in-country transfers. A financial LCOE is the appropriate calculation for a mini grid developer or operator. An economic LCOE represents the cost to the country at large; it is the appropriate calculation for national policy makers. This appendix calculates financial LCOEs.
2. For the HOMER analysis, it is common to set the discount rate equal to the weighted average cost of capital. A rate of 12.5 percent reflects a return on equity of 15 percent and a debt interest rate of 11.4 percent in a project with 30 percent equity and 70 percent debt. These financial terms were deemed appropriate by the consultants for the projects being modeled. Many mini grid projects in Sub-Saharan Africa may not be able to reach this weighted average cost of capital (see Agutu and others 2022).

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APPENDIX K

Boosting Mini Grid Revenues

THE NEED FOR ADDITIONAL REVENUES

Simply building a mini grid and providing a reliable supply of electricity is not sufficient to generate enough revenues to sustain a project. Mini grid developers need to take a proactive role in increasing consumption and revenues, because they will not be able to recover operating costs or achieve commercial sustainability if they fail to do so.

At the very least, cost recovery means covering operating expenses. However, recovering operating costs is not enough for commercial sustainability. To be commercially viable, mini grids must cover their operating costs and the margins above operating costs have to be high enough to cover capital expenditures and company overheads. Without full cost recovery, mini grids will never be bankable (capable of receiving commercial as opposed to just donor financing).

Early evidence shows that many mini grids in Sub-Saharan Africa are probably not even covering operating expenses.[1] A 2020 survey conducted by the Africa Minigrid Developers Association (AMDA) of 288 mini grid projects found that the average revenue per user (ARPU) per month ranged from US$2.96 in Kenya to US$4.83 in Tanzania (AMDA, Economic Consulting Associates, and Odyssey Energy Solutions 2020).[2] AMDA also reported that operating expenditure per user was US$2.50–US$6.00, suggesting that some projects were not covering their operating expenses, let alone their capital and overhead expenses. This phenomenon is almost certainly not limited to Sub-Saharan Africa.

FOUR OPTIONS FOR INCREASING MINI GRID REVENUES

What can a developer do to increase a mini grid's revenues? Four options are (1) raising mini grid tariffs; (2) reducing mini grid tariffs; (3) increasing consumption by households and by commercial, agricultural, and industrial users; and (4) creating nonelectricity revenue streams for mini grid owners/operators.

Raising mini grid tariffs

Raising tariffs does not appear to be a viable option. The developers of the Mokoloki- and Toto-based mini grids sought the regulator's approval of tariffs below levels that could be justified by the regulator's retail-tariff-setting formula (the multiyear tariff order [MYTO] formula). The developers said that they decided not to request the higher tariff costs that could be justified by the regulator's tariff-setting formula, citing potential affordability issues among customers and fears of political backlash. Developers also probably worried that higher tariffs might lead to a decrease in consumption.[3]

Reducing mini grid tariffs

The CrossBoundary Mini-Grid Innovation Lab (2022) has examined the consequences of reducing mini grid tariffs. With subsidy funding from the Rockefeller Foundation, the retail tariffs of five privately owned and operated mini grids in Tanzania were lowered by 50–75 percent, from an average of US$1.26/kilowatt-hour (kWh) to an average of US$0.48/kWh. With continuing subsidies over 3 years, consumption increased by a factor of 1.5 for customers in the highest-consuming category (typically, small businesses) and 19 for customers in the lowest-consuming category (typically, households). Although the lower tariffs led to sustained 150–200 percent increases in electricity consumption over the 3 years, the mini grids' total revenues fell by about 13 percent, indicating that the grids would not be able to sustain the price cuts, because the lower tariffs would not cover the cost of supply, as measured by the levelized cost of electricity. The authors argue that, for price cuts to be commercially sustainable, governments will have to provide additional subsidies to mini grid operators, noting that most governments in Sub-Saharan Africa already provide substantial subsidies to main grid utilities that connect rural customers. They argue that electrification subsidies would have a greater impact if a larger proportion of government subsidies were channeled to private developers.

Increasing consumption by households and by commercial, agricultural, and industrial users

"Growing the load"—encouraging households or businesses to increase their purchases of electricity from mini grids—is important, because rural customers' energy consumption is typically so low that it generates insufficient revenue for developers to sustainably operate their grids (CrossBoundary and Energy 4 Impact 2019).[4] Average consumption per mini grid customer was only 6.1 kWh per month in 2019 and 6.24 kWh per month in 2020 (AMDA, Economic Consulting Associates, and Odyssey Energy Solutions 2020). At a representative mini grid tariff of US$0.50/kWh, this level of consumption generates just over US$3 per month in energy revenues.

A commonly proposed solution for growing the load focuses on productive-use equipment—equipment that customers can use to raise their income (grain grinders, rice hullers, and agricultural water pumping for irrigation are examples). Programs to increase load typically provide loans, technical assistance, and business coaching to mini grid customers to purchase productive-use machinery, which increases electricity demand while increasing customers' ability to pay for it. In some cases, despite latent demand for appliances, high up-front costs and capital constraints prevented customers from purchasing them (CrossBoundary and Energy 4 Impact 2019). Customers are likely to increase their electricity consumption if they are given access to loans to buy electricity-powered appliances. The consumption increase could move mini grid operators closer to full cost recovery. Some customers can benefit from technical assistance to change agricultural or local manufacturing processing practices by acquiring low-cost, clean, electricity-powered, labor-saving technologies.

Productive-use equipment that is used during the daytime not only boosts revenues but can also lower the average cost of electricity production by increasing daytime electricity consumption. Doing so is important because the cost of electricity consumed when it is being generated by solar panels is lower than the cost of electricity cycled in and out of a battery for storage or generated by a backup diesel generator for evening or nighttime use.

Creating nonelectricity revenue streams for mini grid owners/operators

Appliance financing

The CrossBoundary Energy Innovation Lab completed the first phase of an experiment to test whether appliance financing for mini grid customers significantly increases consumption and revenues. Under the experiment—supported by the Rockefeller Foundation—developers were given access to appliance financing for their customers at 4 mini grid sites in Nigeria and at 18 sites in Kenya and Tanzania. In these villages, mini grid customers were given an opportunity to purchase a wide range of appliances on credit.[5] The terms of the loan were a down payment of 20 percent, with the balance paid over 12 months at an interest rate of 2.55 percent per month. (These terms were similar to the loan terms offered by solar home system providers.) The first round of the experiment focused on appliances that could potentially increase households' electricity consumption.

The results were not encouraging. The Energy Innovation Lab concluded that "offering household appliances on set financing terms had no significant impact on mini-grid consumption and revenues" (CrossBoundary Energy Innovation Lab and Energy 4 Impact 2021). Instead of showing an increase, the ARPU fell by 13 percent for the East African mini grids and by 22 percent for the Nigerian mini grids. Considerable variation existed across sites. In East Africa, customers who purchased appliances in the 5 high-performing sites showed an average monthly revenue increase of 42 percent; the 10 low-performing sites showed an average decrease of 15 percent.

Several explanations for these unexpected results are plausible:

- The COVID-19 pandemic reduced demand. The experiment encompassed several months of COVID-19 lockdowns, when customers probably lost income.
- The focus was on household appliances. The first phase of the experiment offered household appliances to consumers. The two most commonly purchased appliances, TVs and speakers, improved the quality of life for households, but they are not likely to have increased their income. In a new phase, the focus shifted to financing productive-use or income-generating machinery.
- Mini grid developers lacked experience selling and financing appliances. Given their lack of experience, it is not surprising that "most mini grid operators . . . . would prefer not to manage an asset financing business, since it sits

outside their core competence as a utility" (Bhattacharya 2020, 8). New firms specializing in financing and providing household and productive-use machinery have emerged. They are experimenting with business models that would allow them to work side by side with developers. Time will tell whether it will be possible to create win-win partnerships between developers and appliance supply and financing companies.[6]

- Consumers' desires may not translate into actual demand. The fact that village households would like to purchase TVs, fans, and other household appliances does not mean they will have enough money to pay for the additional electricity to power these appliances. The CrossBoundary Energy Innovation Lab and Energy 4 Impact (2021, 30) observe that "users of high-consuming appliances found it difficult to maintain consumption, likely due to the impact of additional appliances on their limited income." It seems unlikely that households will be able to increase electricity consumption without an increase in their incomes. Merely providing financing for household appliances is thus not likely to produce significant increases in mini grids' revenues. In addition, a focus on household appliances may increase mini grids' costs, because any added consumption is likely to occur during peak evening hours. Electricity consumed during these hours will usually need to be supplied from more expensive diesel generators or from the expensive drawdown of electricity from batteries.

Financing productive-use/income-generating machines

On average, businesses consume more electricity than households: a grain miller in East Africa consumes about 50 times more electricity than the median residential user (CrossBoundary Energy Innovation Lab and Energy 4 Impact 2021). Productive uses also increase income, increasing financial stability and the likelihood that customers can afford to pay for electricity.

Several factors prevent businesses from replacing diesel-powered machines with electricity-powered machines:

- Some machines may not be suitable for African conditions. PowerGen had to modify internationally available electric mills for them to be viable in Tanzania. The modifications included installing larger pulleys to increase throughput, replacing 1.5-millimeter sieves with 0.8-millimeter sieves to produce flour fine enough to meet local preferences, and installing a soft starter to reduce the surge in power draw when the mill is switched on (CrossBoundary Energy Innovation Lab and Energy 4 Impact 2021).
- Technical assistance and training are required to use electric machinery.
- Mini grid regulations may not explicitly allow developers to recover the costs incurred in a demand promotion and/or financing program. In Tanzania, the Energy and Water Utilities Regulatory Authority recognized the need to assure developers that they would be able to recover demand promotion costs at their retail rates. In its 2019 mini grid regulations, the authority stated that proposed retail tariffs for mini grids "may include on-bill financing such as financing of connection charges, financing of internal wiring, upgrades necessary to minimum electrification requirements, or electrical end-use equipment for productive uses, as well as associated administrative costs" (EWURA 2019, section 47.2). However, if the energy minister unilaterally mandates a major reduction in mini grid tariffs, this targeted regulatory rule will mean little or nothing in practice (refer to box 3.3 for a description of a mandated tariff reduction just before the 2020 Tanzanian presidential elections).

Diversifying into businesses that use electricity

Mini grids can increase their revenues by diversifying into other village-level developer-operated businesses that use mini grid electricity, such as irrigation or water-purification services. When this happens, mini grid operators become their own offtakers.

Mini grid operators could also develop new businesses that produce and sell products and services in addition to their sale of electricity.[7] Doing so has at least three advantages:

1. Revenues are not limited to electricity revenues; mini grids' commercial viability is no longer dependent solely on "selling electrons to others."
2. Mini grids have greater control over the timing of consumption. They can supply electricity to power irrigation services between 8 am and 4 pm, for example, when the mini grids are likely to generate electricity at little or no cost from their solar panels.
3. The sale of services (for example, milling of maize) is less regulated than the sale of electricity.

NOTES

1. Operating expenses equal the "costs of the day-to-day operations and technical maintenance of the mini grid, fuel costs, transportation and logistics, replacement of components and customer service." Fixed operational expenses include "billing and payment collection expense, mobile money infrastructure and data, software platform costs, metering, and land leasing." Central operations expenditures include "legal and central staff labor costs, training expenses and non-site-specific travel expenses" (AMDA, Economic Consulting Associates, and Odyssey Energy Solutions 2020, 34).
2. In their most recent benchmarking survey, AMDA, Economic Consulting Associates, and Odyssey Energy Solutions (2022) report an average ARPU of US$4.29 in 2019 and US$4.44 in 2020.
3. If demand is elastic, a given percentage increase in tariffs will produce a greater percentage reduction in consumption, decreasing total revenues.
4. AMDA (2022) provides evidence that private developers have had some success in growing demand at existing mini grid sites. In 2020, the ARPU for the African mini grids installed in 2017 and 2018 was US$9.89 and US$10.15, respectively. For the mini grids installed in 2019 and 2020, the ARPU was US$4.65 and US$2.19, respectively. The COVID-19 pandemic probably suppressed the 2020 values for both the newer and older mini grids.
5. The most purchased appliances were televisions, speakers, rice cookers, refrigerators, freezers, and satellite decoders. The appliances offered varied by site. A total of 730 appliances was purchased on credit across the 22 sites, which had a total of 2,313 connections.
6. EnerGrow (https://ener-grow.com), a Uganda-based company, will provide asset financing for machinery used in carpentry, metalwork, restaurants/retail services, and tailoring and will provide both warranties and technical and commercial training for businesses that purchase the machinery it sells. Refer to appendix B.
7. Refer to Gonzalez Grandon and Peterschmidt (2019) for a description of the INENSUS KeyMaker model. For a case study of how the KeyMaker model was used at Tanzania's Ukara mini grid, refer to SEforALL (2018).

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ECO-AUDIT

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Traditionally, mini grids have been viewed as "off-grid" systems that are built and operated solely for communities without electricity. The reality, however, is that millions of people in Sub-Saharan Africa and India who *are* connected to the main grid suffer from poor grid reliability ("weak grid"), sometimes with a power supply of less than 4 to 8 hours daily and with frequent disputes over the accuracy of billing. As a backstop, these poorly served customers often find themselves forced to rely on small fossil fuel–powered generators that are noisy, polluting, and expensive to operate.

Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India explores another option: undergrid mini grids. These are mostly solar hybrid–powered mini grids built and operated by private companies in areas already connected with the main electricity grid but facing poor technical and commercial service. This comprehensive book examines how undergrid mini grids can create win-win-win outcomes for retail customers, distribution enterprises, and mini grid developers. Drawing on extensive discussions with pioneering developers, the book showcases detailed case studies from Nigeria and India, shedding light on the challenges and opportunities of interconnected and non-interconnected undergrid mini grids.

The authors address technical issues of grid interconnection and delve into the policy and regulatory considerations crucial for the financial sustainability and success of undergrid mini grids. The book is an invaluable resource for policy makers, energy practitioners, and researchers seeking practical insights to bridge the electricity access gap, empower communities with reliable and affordable electricity, and drive environmentally and commercially sustainable development.

- "The report is rich with insight, not least because the authors have been able to contrast the Nigeria and India approaches taken by the respective private sectors in each country. The five case studies are very valuable. The authors have powerfully illustrated the importance of the policy and regulatory framework and how that translates into investor behavior."

  — Mohua Mukherjee, Senior Research Fellow, Oxford Institute of Energy Studies

- "This great report represents a pivotal turning point in the history of energy and has global implications for the role of mini grids for communities that have been poorly served by main grid utilities."

  — Peter Lilienthal, Founder HOMER Energy

- "This is a tremendous addition to the literature on mini grids and an important guide for all of us practitioners working in this area."

  — James Sherwood, Director of Research & Innovation, RMI | Global South Program

- "This refreshingly honest and open report provides an excellent overview of interconnected and isolated mini grids, as well as a thorough analysis of key ground-level implementation issues in regulation, business, and engineering."

  — Joanis Holzigel, Chief Operating Officer, INENSUS

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