MINIGRIDS IN THE MONEY

SIX WAYS TO REDUCE MINIGRID COSTS BY 60% FOR RURAL ELECTRIFICATION

BY JOSH AGENBROAD, KELLY CARLIN, KENDALL ERNST, AND STEPHEN DOIG

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Image © RMI. RMI site visit in Kenya

EXECUTIVE SUMMARY

More than 600 million people—65% of the sub-Saharan African population—lack electricity access. Hundreds of millions more have only an unreliable and intermittent supply, at best. Across much of Africa, many communities and businesses without reliable grid electricity have turned to expensive, noisy, polluting, unreliable electricity from diesel- or petrol-powered generators (i.e., gensets).

The traditional path to bringing power to the unserved millions is to expand the electricity grid, building new fossil-fueled power plants and running transmission and distribution lines to far-flung villages, farms, and homes. That model has worked in the developed world, where strong government agencies and locally organized cooperatives have driven electrification. But the approach has not worked as well in sub-Saharan Africa and other developing regions for several reasons, including:

- high infrastructure costs
- low ability of end-users to pay
- disproportionately small end-use demand in villages
- unreliable and intermittent electricity supplied via grid extension.

Today, innovative business models using modern technologies such as solar photovoltaics (PV) and low-cost batteries are emerging as an effective way to provide off-grid power in rural areas, enabled by developments such as mobile money and pay-as-you-go financing. Rocky Mountain Institute (RMI) and others have already seen these effects on a small scale in communities that have recently adopted innovative off-grid power approaches, such as solar home systems or larger solar-based minigrids.

At the smallest scale, solar lanterns and home solar systems can light a house, run a radio, recharge a mobile phone, and, increasingly, power small appliances such as fans and televisions. The market for these solar home systems is growing rapidly. Equally important, the solar lantern and home systems have proven to be a viable business and market opportunity, attracting hundreds of millions of dollars in investment.

Despite the success of solar lanterns and solar home systems, another critical leap must be made: providing not just watts of electricity but kilowatts. People need not only solar lanterns and mobile phone chargers but also appliances and equipment that support greater economic growth and quality-of-life improvements. Minigrids can bridge this critical gap between smaller, solar-powered off-grid efforts and the hundreds of millions of people traditional grid extension has failed to reach.

Once people have access to larger amounts of electricity, they can use cassava grinders, welding equipment, sewing machines, band saws, refrigerators, water pumps, washing machines, and scores of other important devices. That, in turn, puts more money into people's pockets, enabling local regions to grow in a virtuous cycle of development that many African governments are targeting.

For this reason, there is currently a vital role for minigrids—small-scale distribution networks with local generation based primarily on solar PV power, backed up with batteries or gensets for reliable 24/7 power. However, although successful examples exist, minigrids have so far largely failed to scale across the subcontinent. Addressing and overcoming barriers will thus be critical for minigrids to deliver benefits for the populations that need them most.

BARRIERS TO SCALING RURAL MINIGRIDS

Four key barriers stand in the way of using minigrids to achieve widespread rural electrification:

1. **Most minigrids are still too expensive.** Although several companies are now developing standardized designs, most current minigrids are unique, custom installations. As a result, the typical levelized cost of energy (LCOE) for a well-run minigrid today is at least $0.60 per kilowatt-hour (kWh).

2. **Minigrid-produced power is underutilized.** The typical rural household lacks the resources to buy water pumps, electric irons, refrigerators, and other devices and appliances—even sometimes a fan—that would put to use more of a minigrid's potential electricity generation. Poor utilization rates thus further drive up the resulting cost per unit of electricity sold because a smaller number of kilowatt-hours of consumption share the up-front capital and ongoing operational costs. Moreover, the demand that does exist may not match the generating profile of a solar-based minigrid.

3. **Financing is expensive or unavailable.** Minigrid companies have struggled to secure equity, or either concessional or commercial debt, keeping them from scaling up their operations. In addition, any financing that is available is expensive, with rates of commercial debt available to developers typically 15% or more in sub-Saharan Africa.

4. **Regulatory and policy barriers slow progress and increase costs.** Slow, unclear, or unpredictable licensing and tariffs, as well as requirements that limit the prices that can be charged for electricity, add further challenges and risks.

COST-REDUCTION PATHWAYS FOR RURAL MINIGRIDS

Our analysis has identified one pathway by which minigrid costs can be reduced by 60%. This cost reduction would rapidly accelerate market growth for minigrids by cutting the LCOE of minigrid-produced power from between $0.60 per kWh and $1.00 per kWh today, to $0.25 per kWh by 2020:

1. **Reduce costs of minigrid hardware.**
   a. Leverage ongoing hardware cost declines
   b. Pursue bulk purchasing and streamlined procurement
   c. Use standardized designs and simplified construction methods
   d. Use a "minigrid-in-a-box" approach

2. **Ensure that the electricity generated is fully utilized through demand stimulation and optimized load management.**
   a. Locate minigrids near productive uses of energy—operations such as grain mills, garment factories, hospitals, or a business district of shops—to ensure sufficient demand and revenues
   b. Find ways to create or stimulate demand sustainably, for example, by providing financing for people to buy electric motors for grain mills or electric pumps in addition to buying the electricity that runs them
   c. Proactively manage demand—especially flexible loads—to more fully utilize/absorb variable renewable generation

3. **Focus on customer acquisition and relationship management.** Work closely with local communities and local actors. Not only can local people be trained for many jobs connected with minigrids but also communities could take over management and even ownership roles. This approach better aligns incentives for finding loads, signing up new customers, ensuring security, siting, and improving collections. Some level of community ownership

will also keep part of profits in the local community, creating a virtuous cycle for further economic development and new electricity demand. Seek partnership opportunities with local actors. Local actors such as nonprofit agencies working within communities have knowledge and relationship resources that can ease the project development effort.

4. **Cut costs of constructing and operating minigrids.** Most minigrids are currently constructed one at a time in far-flung locations. Building many minigrids in closely spaced clusters, however, is far quicker and more efficient. We envision clusters of dozens of sites separated by no more than two to three hours of travel distance. This setup would make it easier to form strategic partnerships to take advantage of economies of scale and to tap more into local knowledge and labor, increasing community engagement.

5. **Enable low-cost financing.** Most current minigrid projects have been funded by grants, by equity, or with greatly subsidized interest rates. Those sources of financing are crucial because commercial loan rates available for minigrids in sub-Saharan Africa are too high, at 15%–20%, for minigrids to get off the ground. Increasing the availability and reducing the cost of capital for minigrid projects will be crucial. These goals can be accomplished through:
    a. Standardizing different parts of minigrid financing, including the supply chain, project finance, and consumer finance
    b. Gaining grant funding for three to five projects in each market that can prove strong customer demand and provide data on load growth over time and customer ability and willingness to pay
    c. Engaging early with subsequent funding rounds to clarify necessary proof points to de-risk and unlock future funding
    d. Providing additional financing to buy appliances and productive services, thus helping customers increase demand while diversifying and increasing investor returns

6. **Reduce regulatory barriers, costs, and risks.** Overall, customs duties, value-added tax, and local taxes can add almost 50% to the total hardware cost. Unexpected tariffs quickly dissolve profit margins and make costs unaffordable for consumers. Perhaps more challenging, rules around setting tariffs (the price customers will pay for a unit of electricity) present another set of risks and uncertainties. In some countries, minigrids aren't allowed to charge more for electricity than the rates of the central grid—a major problem when the grid is heavily subsidized. Just getting tariff approval can be a long, expensive process.

01

THE OPPORTUNITY TO TRANSFORM RURAL AREAS WITH MINIGRID ELECTRICITY

Image © RMI. Romoke Taiwo's fish farm in rural Nigeria now has a refrigeration, thanks to a minigrid

THE OPPORTUNITY TO TRANFORM RURAL AREAS WITH MINIGRID ELECTRICITY

Electricity access, reliability, and cost remain challenges across much of sub-Saharan Africa

Kimberley, South Africa, known as the Diamond City, got its first electric streetlights in 1882, nearly a decade before London and around the same time as Paris and Berlin. South Africa got its first central power station in 1891, and municipally served electricity arrived in 1892, just 10 years after the famed Pearl Street Station in New York City came online.[1] Yet despite these early advancements, electrification across sub-Saharan Africa has since lagged behind the rest of the world.

More than 600 million people—65% of the sub-Saharan African population—lack electricity access. Hundreds of millions more have only an unreliable and intermittent supply, at best. The need—and the demand—is so great across much of Africa (and the rest of the developing world) that many communities and businesses without reliable grid electricity have turned to expensive, noisy, polluting, unreliable electricity from diesel- or petrol-powered generators (i.e., gensets).

For example, Nigeria alone has a staggering total of 10 gigawatts of genset electricity, enough to power 1 billion LED bulbs. People pay more than $0.50 per kilowatt-hour (kWh) for that electricity, 2.5 times or more than the average residential electricity price in countries such as France, Australia, Korea, Argentina, and the United States.[2]

As a result, bringing reliable, affordable electricity to vast areas of Africa would profoundly improve lives. It would lift productivity and incomes, open the door to new businesses such as grain mills and welding shops, keep milk and fish from spoiling, even just allow a community to gather around a TV, cold drinks in hand, to cheer on their favorite football team.

Early efforts with renewably powered minigrids have generated promising results

Until recently, electrification efforts were limited by the high cost of local generation at relatively small scale and by the slow and often equally expensive expansion of the electricity grid led by cash-strapped electricity utilities and governments. New technologies are beginning to enable solar power to provide off-grid power to rural areas, and innovative business models are emerging, enabled by developments such as mobile money and pay-as-you-go financing.

Rocky Mountain Institute (RMI) and others have already seen the effect of these new technologies and business models on a small scale in communities that have recently adopted innovative off-grid power approaches, such as solar home systems or larger solar-based minigrids. Consider the following examples:

- When many residents of the Nigerian village of Wamu got 10-watt (W) solar home systems, each with a few lights and a cell phone charger, the changes were swift. Grades for girls rose because the girls could study at night after cooking and doing other chores during the day. Farmers were able to continue to dry their yams and maize long into the evening, under the glow of lights, boosting productivity. New shops and businesses sprang up, using their new power to provide gathering places and services.[3]

- In Obayantor, in Nigeria's Edo State, a 37.8-kilowatt (kW) solar minigrid built with support from the United Nations Development Programme is now supplying electricity to 200 homes, a welder, several mills for grinding crops, a water well, and a growing business using refrigerators and freezers for cold storage. In Sagbo Kaji, the owner of the Embassy Clippers barbershop used to burn 10 liters of expensive fuel a day. He now spends one-fifth as much on solar electricity from the minigrid system.[4]

- At the vast Sabon Gari Market in Kano, Nigeria, a recent switch from expensive intermittent power from hundreds of gensets to reliable minigrid electricity led shop owners to expand and invest in air conditioners and other equipment. "I'm very excited about how entrepreneurial people will become once they have a power supply," says Damilola Ogunbiyi, managing director of Nigeria's Rural Electrification Agency (REA). "There is a direct correlation between electric power and economic growth."

- In Kenya's Kitonyoni Health Centre, nurse Mercy Twili now delivers babies at night in the glow of electric lights instead of holding a cell phone in her teeth. In one set of Kenyan minigrid sites, the revenues of local, rural businesses increased by 25% when they switched from diesel power to electricity.[5]

- In Sierra Leone, the small shops along the rusty red dirt main street of Segbwema once used costly and unreliable diesel generators to chill their bottles of Coca-Cola and local ginger ale for a few hours each day. Then in 2017, Segbwema got a solar and battery system that sends electricity to dozens of businesses and homes. Now, Ismail Tumu, a local shop owner, has added a television for showing football games and an entertainment system. He offers reliable cell phone charging in addition to selling cold beverages. Profits have doubled, he told our team.[6]

Grid extension efforts can be too slow and expensive to effectively and efficiently reach many off-grid populations

The traditional path to bringing power to the unserved millions is to expand the electricity grid, building new fossil-fueled power plants and running transmission and distribution lines to far-flung villages, farms, and homes. This model has worked in the United States, Europe, and the rest of the developed world, where strong government agencies and locally organized cooperatives have driven electrification. But the approach has not worked as well in sub-Saharan Africa, India, and other developing regions for many reasons:

1. **Infrastructure costs are high.** Infrastructure costs can be as much as $20,000 per kilometer (km).[7] That quickly becomes a $1 million bill to connect a single town a modest 50 km from a power plant or main transmission line.

2. **End-users' ability to pay is low.** Incomes are low, so most people can't afford to pay the market rate for electricity, let alone one-time connection charges that can add up to several months' worth of income.

3. **Total end-use demand in villages is usually disproportionately small.** Large potential users of electricity, such as lumber mills and garment factories, are rare in rural sub-Saharan Africa. Thus, the overall electricity demand, even if people could afford power, would be small. In other words, there is a serious mismatch between the large amounts of electricity supplied by the traditional grids and the relatively small amounts of demand needed throughout rural areas.

4. **Even when grid extension reaches newly electrified populations, that energy is often unreliable and intermittent.** Grid power often provides electricity for just a few hours a day. For example, an official from the West African Institute for Financial and Economic Management in Nigeria told the New York Times in 2015 that most companies in that country don't have four hours of power per day from the national grid.[8]

Small-scale solutions, such as solar lanterns, have helped but are not enough

The struggles of the traditional grid to provide reliable electricity for millions of people, combined with the growing demand for power, have opened the door to new, off-grid solutions. At the smallest scale, solar lanterns and home solar systems can light a house, run a radio, recharge a mobile phone, and, increasingly, power small appliances such as fans and televisions. And the market for these solar home systems is growing rapidly; at least 11 companies are now selling systems in Africa, with more than a million customers combined.[9]

Equally important, solar home systems have proven to be a viable business opportunity, attracting hundreds of millions of dollars in investment. In a typical arrangement, customers in Tanzania make an initial payment of about $13 for a panel, a battery, LED lights, a phone charger, and a radio. Then, they pay about $8 per month for three years, which is less than they had been paying for kerosene or other fuel. After three years, they own the system outright.

For some rural areas, where there is little or no commercial activity, these stand-alone solar solutions are a major step forward, providing light in the evenings and power to charge mobile phones. In much of rural Rwanda, for instance, small 5 W to 200 W systems, which have already been installed in over 180,000 homes, can meet the need for power because there are virtually no grain mills, shops, or other commercial uses.[10]

Minigrids fill a critical gap, providing cost-effective, reliable, clean electricity to power economically productive uses that go above and beyond supporting basic life needs

Despite the success of solar lanterns and solar home systems, another critical leap must be made: providing not just watts of electricity but kilowatts. People need not only solar lanterns and mobile phone chargers but also appliances and equipment that support greater economic growth and quality-of-life improvements. As we described in our 2017 report *Energy Within Reach*, minigrids can bridge this critical gap between smaller, solar-powered off-grid efforts and the hundreds of millions of people traditional grid extension has failed to reach.[i] This report builds on that foundation based on our further analysis, research, and on-the-ground work with minigrid developers and African governments.

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[i] The role that minigrids can fill and the opportunity they create are described in RMI's report *Energy Within Reach: Growing the Minigrid Market in Sub-Saharan Africa*. (Josh Agenbroad, Kelly Carlin, Stephen Doig, Claire Henly, and Eric Wanless. Rocky Mountain Institute, January 2017. **https://www.rmi.org/insight/energy-within-reach/**)

Once people have access to larger amounts of electricity, they can use cassava grinders, welding equipment, sewing machines, band saws, refrigerators, water pumps, washing machines, and scores of other important devices. That, in turn, puts more money into people's pockets, enabling local regions to grow in the same virtuous cycle of development that transformed the rural economies of Europe, the United States, and much of Asia. In fact, gross domestic product (GDP) closely tracks per capita electricity use,[11] so a key development goal should be to boost the average power per person.[ii] For this reason, there is currently a vital role for minigrids—small-scale distribution networks with local generation based primarily on solar photovoltaic (PV) power, backed up with batteries or gensets for reliable 24/7 power (see **Figure 1**, page 14).

In many communities currently unserved or underserved by central grids, minigrids can actually provide power at a lower cost than people are *already* paying for alternatives such as small gasoline or diesel motors and generators. In the rural Nigerian village of Onyen-Okpon, we calculate that a solar-based minigrid could save the community $100,000 per year compared with the genset power it currently uses—while providing far more reliable and cleaner power throughout the day and evening. The townspeople are so confident about the benefits that they are willing to dig into their own pockets to help pay for it, farmer Finian Oyem told us.

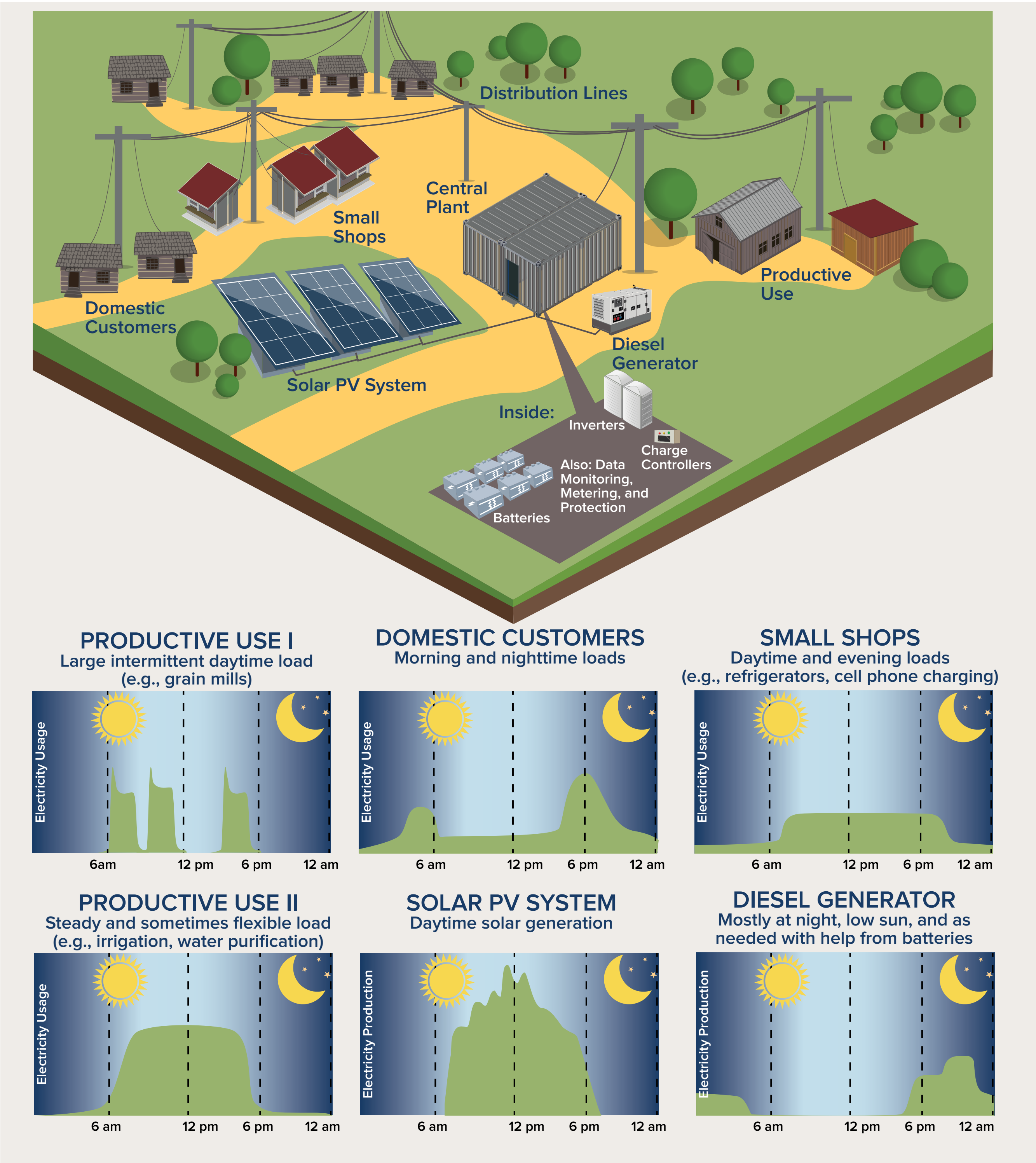
Although successful examples exist, minigrids have so far largely failed to scale across the subcontinent. Addressing and overcoming barriers will thus be critical for minigrids to deliver benefits for the populations that need them most.

Image Courtesy: USAID, Alhassan and Musah Zakari Work for Gundaa Produce Company, Ghana

[ii] With the caveat that increased energy efficiency can boost GDP without increasing energy use.

FIGURE 1

HOW MINIGRIDS SERVE COMMUNITIES



02

CHALLENGES TO SCALING RURAL MINIGRIDS

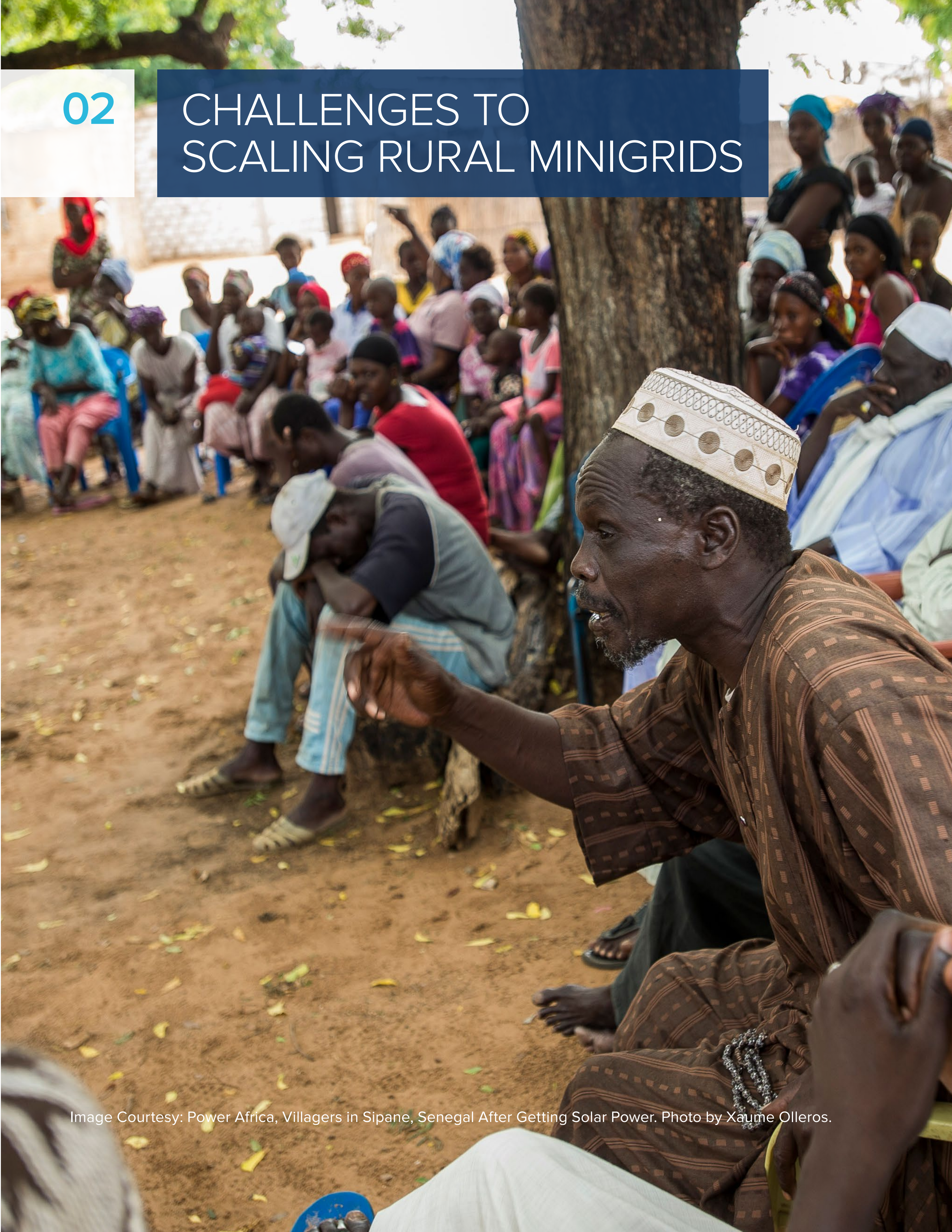


Image Courtesy: Power Africa, Villagers in Sipane, Senegal After Getting Solar Power. Photo by Xaume Olleros.

CHALLENGES TO SCALING RURAL MINIGRIDS

We are by no means the first to see the enormous potential of minigrids. Over the past two decades, foundations and development partners have invested more than $300 million in the solar-based approach, with hundreds of projects in operation across the developing world. For example, since 2011, PowerGen has built dozens of minigrids in Kenya and Tanzania. Eight companies have developed 10 commercial minigrids in Nigeria, in addition to numerous donor-driven projects across the country.[12] And in India, OMC Power has pioneered using the "anchor" load from a telecom tower to ensure sufficient demand for a minigrid that can also power surrounding homes and businesses. With backing from The Rockefeller Foundation, OMC has built more than 100 small minigrids in India and is planning to expand to Africa in a partnership with Japanese conglomerate Mitsui. Enabling regulations already exist in many leading markets and are being tested and refined with experience.

Still, four key barriers stand in the way of using minigrids to achieve widespread rural electrification:

1. **Most minigrids are still too expensive.** Although several companies are now developing standardized designs, most current minigrids are unique, custom installations. Buying individual components, without the purchasing power that comes from large scales, means that up-front hardware costs are high. As each project has a unique design, project development and construction costs are also high. Our detailed analysis shows that up-front costs can exceed $1 million for a 200 kW peak load solar minigrid with diesel and battery backup. Operational, customer service, and overhead costs add up to an additional $100,000 per year. As a result, the typical levelized cost of energy (LCOE) for a well-run minigrid today is at least $0.60 per kWh (see **Understanding Minigrid Costs**, page 17).

2. **Minigrid-produced power is underutilized.** Poor utilization rates drive up a minigrid's cost per unit of electricity sold; in order to recover the costs of their investment and ongoing operating costs, developers have two choices: either sell electricity at a higher cost or sell more units of electricity. If developers sell too little power, then they may be forced to sell power at an unaffordable rate. But the typical rural household lacks the resources to buy water pumps, electric irons, refrigerators, and other devices and appliances—even sometimes a fan—that would put to use more of a minigrid's potential electricity generation. In many cases, these products aren't even available in rural areas. Many households will use only very small amounts of electricity for lights and sometimes a radio. They may also lack the ability to pay for electricity much of the year until the harvest comes in. Moreover, the demand that *does* exist may not match the generating profile of a solar-based minigrid, which produces its peak amount of electricity during cloudless afternoons.

3. **Financing is expensive or unavailable.** Grants have funded most projects to date, but this source will be insufficient to meet the levels of investment required. The International Energy Agency (IEA) estimates that over $100 billion will need to be invested in minigrids by 2030 to achieve universal energy access.[13] Yet minigrid companies have struggled to secure equity and low-cost debt, limiting their ability to scale operations. In addition, any financing that is available is expensive, with rates of commercial debt typically 15% or more in sub-Saharan Africa.

4. **Regulatory and policy barriers slow progress and increase costs.** Slow, unclear, or unpredictable licensing and tariffs, as well as requirements that limit the prices that can be charged for electricity, add further challenges and risks. In addition, uncertainty about where the traditional grid will

be expanded creates risk that the grid will arrive sooner than expected, which dissuades developers and their investors. Minigrids typically cannot compete with a national grid, for which generally low tariffs are enabled through government subsidies or the economies of scale achieved with aggregating demand across a much larger number of customers. And while minigrids could be integrated with the grid in the future, that integration may face regulatory and technology-compatibility hurdles.[iii] Uncertain policies mean that developers may avoid some of the best sites with existing economic activity and substantial demand because those sites are often located near grid-connected areas. Further, unforeseen problems can arise. One minigrid project we investigated ran afoul of government regulators, who held up the project for over six months by impounding at the border the meters needed to connect customers.

Understanding Minigrid Costs

LCOE can be used to approximate and compare cost of service to customers for a given system configuration and operation. LCOE allows comparisons across different types of power, such as grid electricity or genset power, and is calculated by adding all the up-front and operating costs (including the cost of capital), then dividing by how many kilowatt-hours will be sold to customers. Any underutilization of the capacity raises cost. Sell less electricity, and LCOE rises.

Dollars per watt is another common metric for benchmarking minigrid cost, but this metric can be misleading. For example, systems with more battery and solar PV capacity will have higher up-front cost but lower operating cost. Also this metric does not take into account utilization rates, load profiles, or capital costs. Similarly, many organizations consider cost per connection as a metric. Although this emphasizes the value of energy access, it may encourage the construction of financially unsustainable systems that do not target commercially viable customers and revenue models. It is important to consider both LCOE and alternative metrics together.

Our analysis shows that the best-run minigrids today still have an LCOE of at least $0.60 per kWh (see **Figure 2**, page 18), making the electricity too costly for widespread use without subsidy. Electricity from minigrids must compete with the cost of running a small gasoline or diesel generator ($0.35 per kWh–$0.70 per kWh), the cost of power from the grid ($0.10 per kWh–$0.20 per kWh), and new customers' ability and willingness to pay (e.g., many customers cannot afford even the cheapest pay-as-you-go options for stand-alone solar systems at $1.25 per week–$2.50 per week). In **Figure 2**, we see that 60% of the cost of service from minigrids is due to up-front costs and 40% are ongoing costs.

Figure 3 gives a more detailed look at up-front costs. About 18% of the cost is for the solar panels, inverters, and other electronics; 30% is for the lead-acid batteries; and another 18% is for the diesel generator system. Building and operating minigrids requires a lot of steps—each of which adds costs. In addition to the expense of the hardware, the up-front costs include construction costs, duties and fees, and delays (**Figure 3**, page 19).

[iii] However, despite these hurdles, there is a significant opportunity to improve service in many grid-connected rural communities, as discussed in RMI's report *Under the Grid: Improving the Economics and Reliability of Rural Electricity Service with Undergrid Minigrids*. (Sachiko Graber, Patricia Mong, and James Sherwood. Rocky Mountain Institute, November 2018. **www.rmi.org/insight/under-the-grid/**).

FIGURE 2

$0.60 PER KWH IS THE TYPICAL COST FOR A LARGE, WELL-RUN MINIGRID TODAY

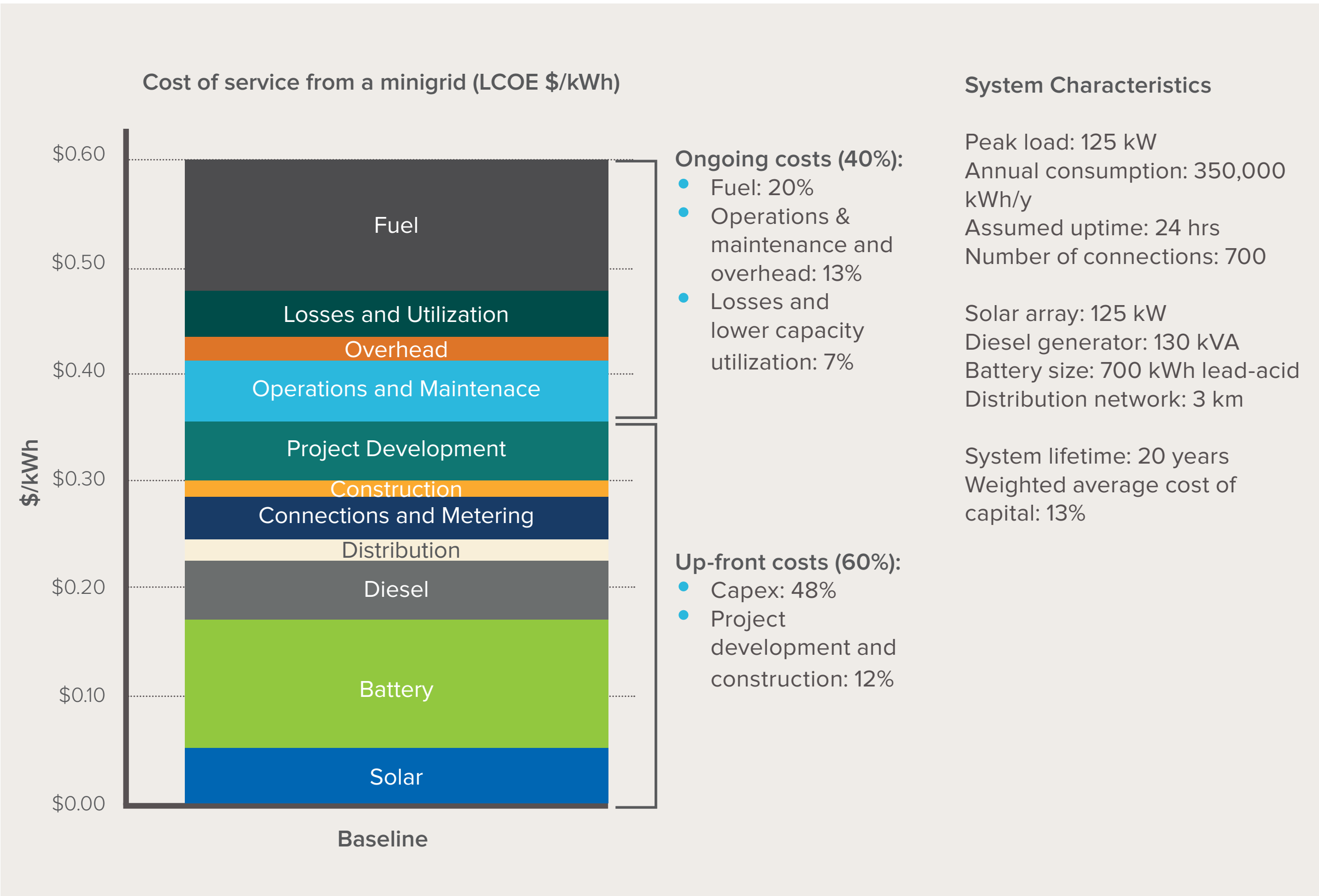
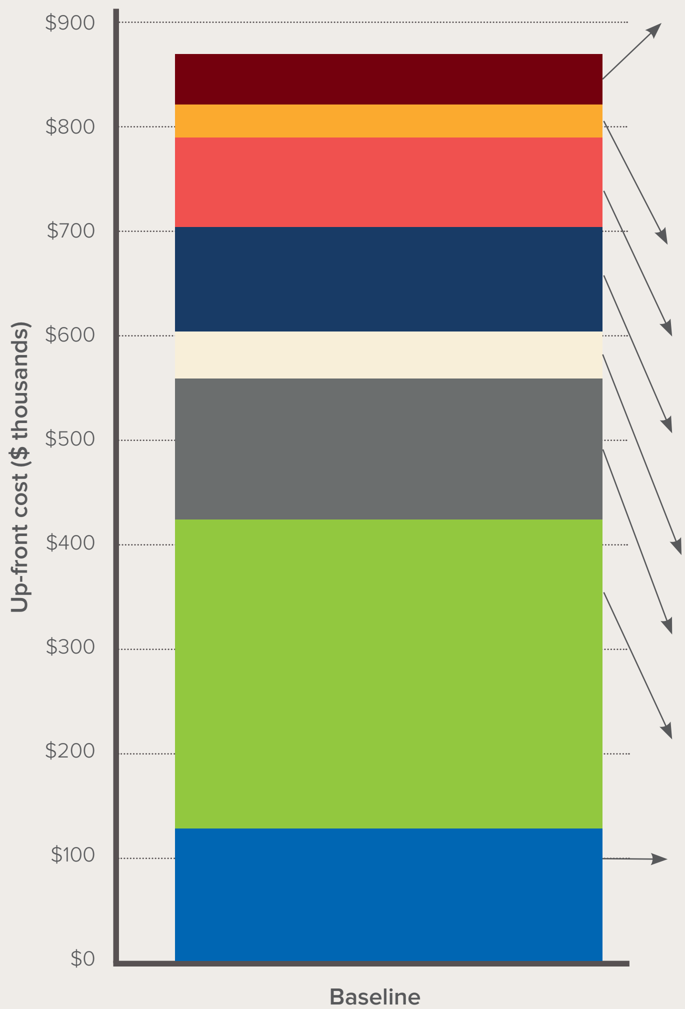


Figure 4 on page 20 shows operating costs. The biggest costs are for fuel (58%); various types of losses, such as parasitic loads for cooling (16%); and on-site operations management (8%). Even small tasks such as periodic visits by headquarters staff can be expensive because most current projects are widely scattered. One Nigerian minigrid company estimates that, because of the large distances traveled, each visit to one of its West African minigrids costs several hundred dollars. Managing customer relations is quite inexpensive, but we would argue that companies might do well to increase it because it affects other big cost contributors such as system utilization, non-tech losses (e.g., non-collection), and demand stimulation. Fuel cost can be reduced by installing more batteries plus solar, but we find that at today's prices, this approach leads to a higher LCOE overall. A detailed understanding of minigrid costs makes it possible to develop strategies for reducing those costs.

FIGURE 3
UP-FRONT COST IS DRIVEN BY CAPEX EXPENDITURES



Up-front soft costs (6%):
- Predevelopment costs include labor to select sites and perform initial customer engagement
- Engineering labor is calculated for system design, construction supervision, and financial modeling
- Site delays are calculated as captive capital and idle labor

Construction and installation costs (4%) for all components based on labor cost and time estimates

Duties and fees (10%): include customs duties and VAT for imported capex except solar

Connections (weighted average of 1/3 phase of $49/conn.) **and meters (12%)** (weighted average of 1/3 phase of $95/conn.) capex

Distribution capex (5%): Low voltage 1/3 phase distribution at $1,550/100 m

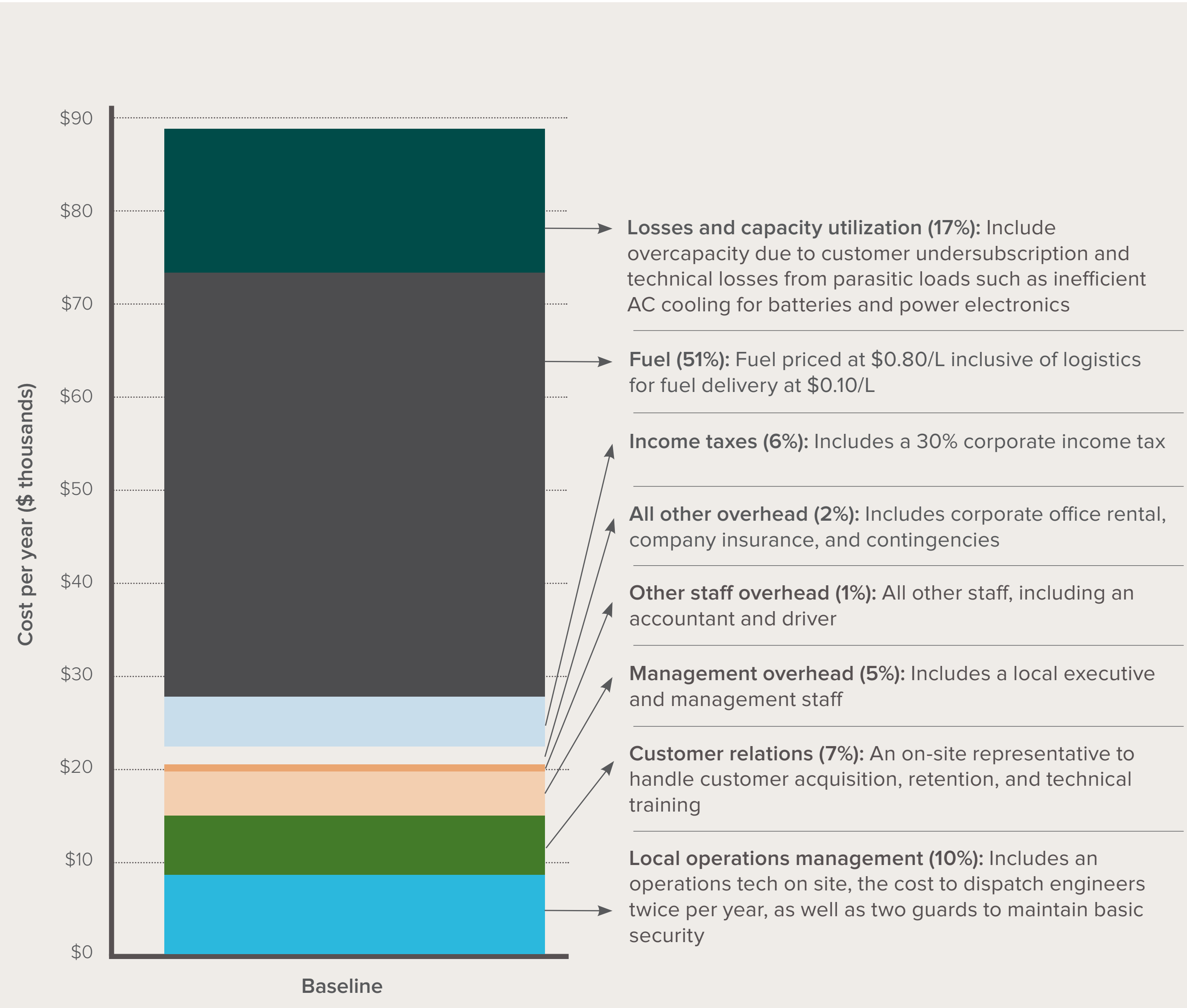
Diesel capex (16%): $1,050/kW includes generator, housing, and replacement (8 year) cost

Battery capex (34%): $390/kWh for lead-acid batteries, housing, and replacement (5 year) cost
Battery inverter cost: $175/kW

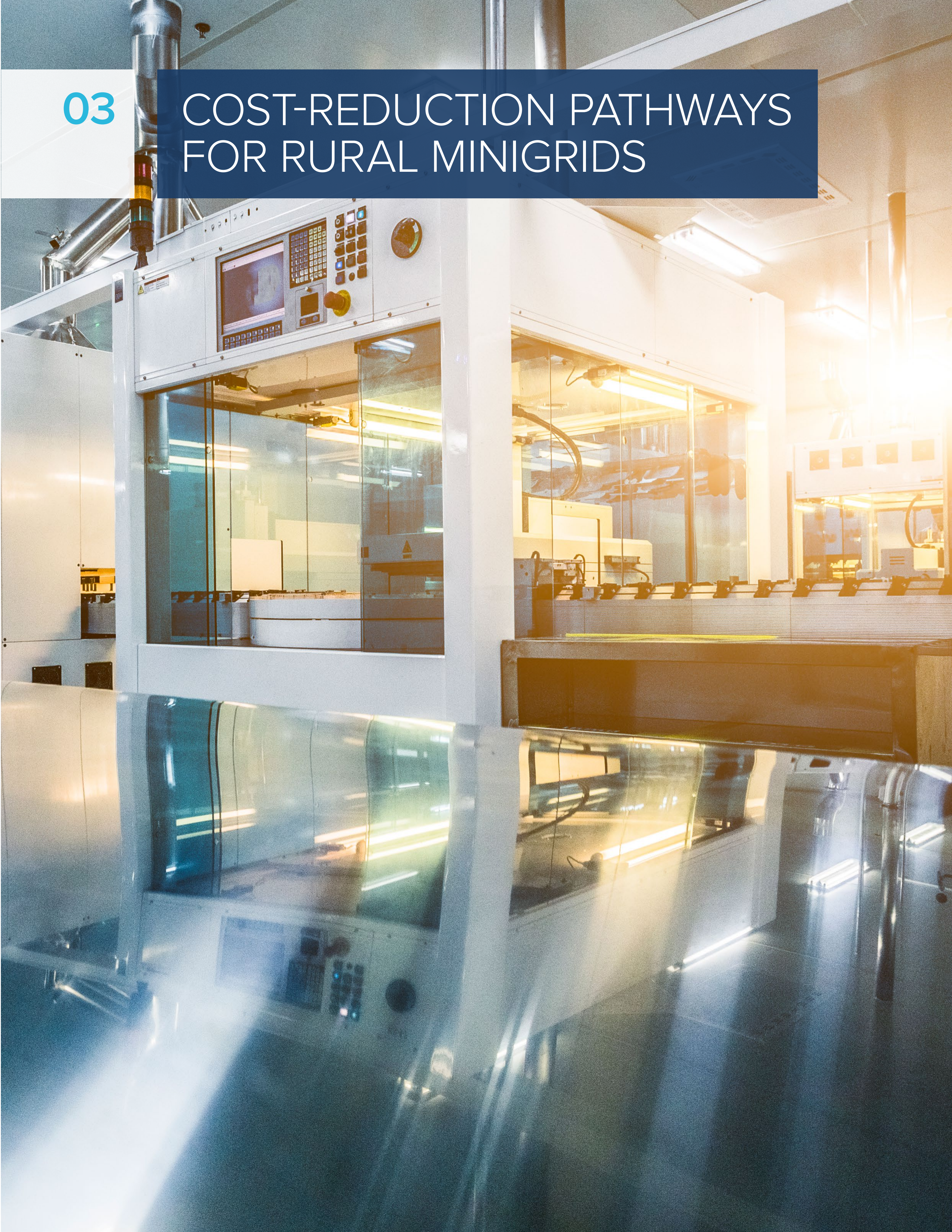
Solar capex (18%): $1,020/kW includes module, inverter, racking, foundation, and balance of systems. Graph includes spare parts for all capex and sub-distribution for all generation

FIGURE 4

FUEL AND UNDERUTILIZATION OF ASSETS DRIVE ONGOING COSTS



03 COST-REDUCTION PATHWAYS FOR RURAL MINIGRIDS



COST-REDUCTION PATHWAYS FOR RURAL MINIGRIDS

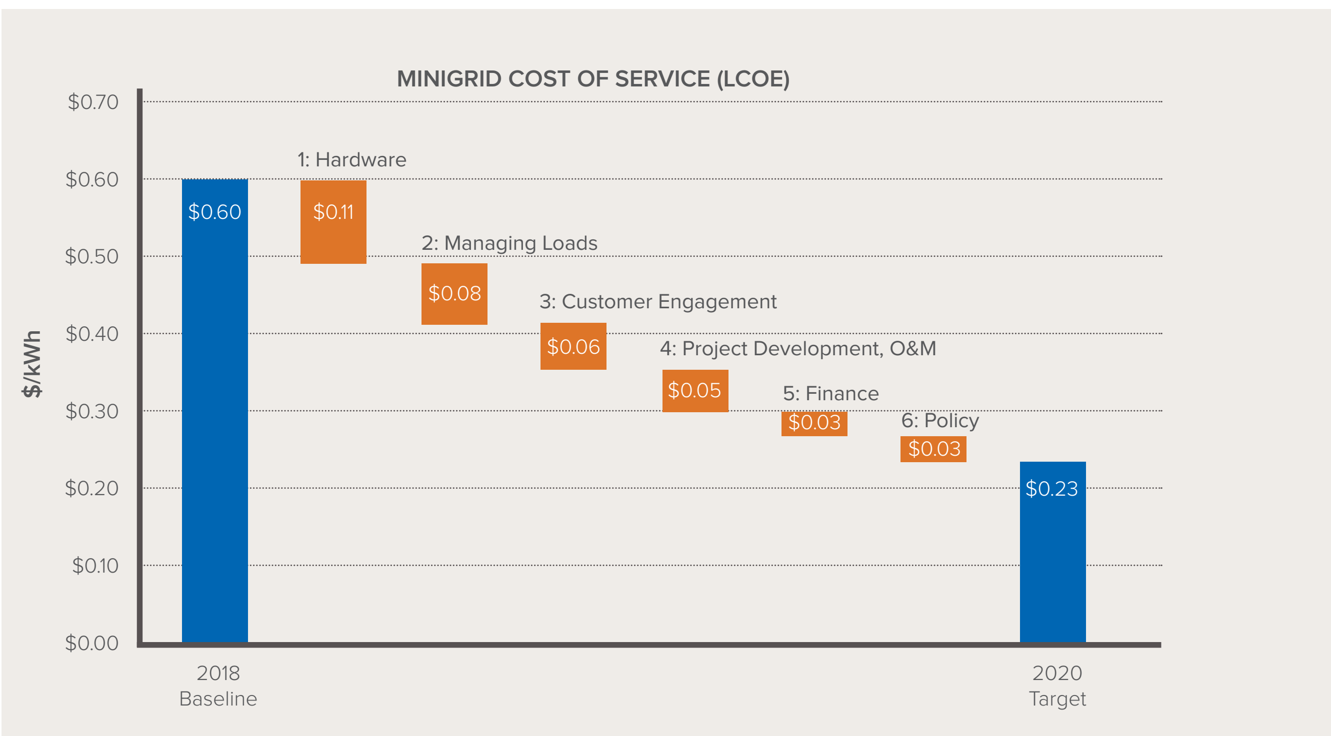
Despite barriers, our analysis has identified six key ways that minigrid costs can be reduced by 60%, as Figure 5 shows. This reduction would rapidly accelerate market growth for minigrids, mainly by cutting the cost of minigrid-produced power from between $0.60 per kWh and $1.00 per kWh today to $0.25 per kWh by 2020.

At that price, minigrid electricity would be far cheaper than the power from the small, noisy, and polluting petrol and diesel generators that are ubiquitous across Africa and would be transformative in the economic activity it would unlock. In addition to providing a multibillion-dollar business opportunity for builders and operators, such minigrids will boost economic growth, strengthen communities, improve health and education, and fight climate change by cutting greenhouse gas emissions.

Our bottom-up analysis shows one possible pathway to achieve these 60% cost reductions (**Figure 5**). See the Appendix for a detailed methodology and list of assumptions. Other possible solution pathways exist, depending on the specific market and company strategy, but this analysis provides a generalized approach to reducing cost.

FIGURE 5

MINIGRID COST CAN BE REDUCED 60%



1. REDUCE COSTS OF MINIGRID HARDWARE.

Leverage ongoing hardware cost declines: The costs of solar panels, inverters, and other components have been declining rapidly over the past decade. For example, the LCOE of PV decreased by 69% between 2010 and 2016, according to the International Renewable Energy Agency.[14] For utility-scale solar in particular, costs have declined 86% between 2009 and 2017—down to $0.05 per kWh—according to Lazard.[15] Such steep declines are expected to continue. By 2040, Bloomberg New Energy Finance forecasts the LCOE of PV will drop another 66%. Minigrid developers will benefit from this larger trend. We estimate that the costs of the hardware needed for minigrids (solar panels, inverters, batteries, etc.) will decline 18% in the next three years.

Pursue bulk purchasing and streamlined procurement: As the pace of minigrid construction accelerates, developers will be able to buy megawatts of capacity, rather than kilowatts, at a time. Based on conversations with wholesalers, we estimate the combination of bulk purchasing and streamlined procurement will shave another 15% in costs.

Use standardized designs and simplified construction methods: Currently, the typical minigrid system is assembled on-site, with workers painstakingly connecting perhaps six separate inverters and other electronic components to each individual solar panel and the battery or generator backup system. Then the workers do something similar, but also customized, at the next site. Refining the minigrid-in-a-box solution drastically reduces labor and hardware costs, as explained below.

Refine minigrid-in-a-box designs: Design the electronics with correctly sized inverters already connected to the other necessary components. Ideally, the electronics and solar panels would be "plug and play" and would be available as different-sized commercial products, much as it is now possible to buy heating, ventilation, and air-conditioning units with a wide range of capacities.

Component parts from the global supply chain could be preassembled in a central facility before being transported to the field for installation. We expect that the minigrid in a box would be developed by larger upstream equipment suppliers with large research and design budgets and access to the global supply chain. Over time, these preassembled units could cut costs through lean design, volume purchasing, and competitive procurement.

For example, in India, the Institute for Transformative Technologies (ITT), with backing from The Rockefeller Foundation, has designed and built prototypes of what it calls a "utility in a box." ITT's approach aims to streamline minigrids using a module that combines built-in electronics with a 10 kW PV array that can be scaled-up depending on the situation. In East Africa, minigrid developer PowerGen has experimented with a similar approach.

Major minigrid electronics suppliers are also working on standardized and modular systems that could be delivered in a standard metal shipping container. The container could include the panels, inverters, batteries, and charge controller. Once delivered, the solar panels would be pulled out and mounted, and the containers could house all of the electronic equipment.

We expect that after a minigrid developer works with communities to find a site, estimate loads, and get the necessary permits, the developer soon will be able to call a supplier and order a modular system with the right capacity. A supplier with a local presence would then gather all the necessary components, wire them together as much as possible, then pack them into a shipping container for delivery. There are also opportunities for companies or nonprofit groups to do their own design and assembly and act as middlemen to sell standardized systems into the market.

Both scenarios will bring reductions in costs through large-scale purchasing and by optimizing supply chains. The standardized approach will also lower the amount of time needed for engineering by at least one-third, and the installation time by 80%. Solar PV and racking might also be standardized with some factory preassembly.

Even lower costs might be possible through innovative new mounts for the solar panels. Typically, the panels are attached to steel frames driven into the ground or secured in concrete-filled holes. A company named Powerfield, however, has developed inexpensive, lightweight U-shaped plastic containers that are held in place with a heavy, natural material like sand, dirt, or rocks. In tests at the National Renewable Energy Laboratory, an inexperienced six-person crew was able to install 56 panels in less than five hours, far quicker than today's standard.[16]

Our analysis shows that the combination of standardized and modular minigrids and larger-scale deployment will lower the final cost of the minigrid power by $0.11 per kWh, or about 20% of the total LCOE. Realizing these reductions, however, requires both a whole-system design approach and an open and competitive procurement process. Currently, many local entrepreneurs can't buy solar panels and other equipment at the low prices available to big developers in Europe or the United States.

As we identified at a March 2018 minigrid design workshop in Lagos facilitated by RMI, there are several important questions and ideas for moving forward to achieve these hardware cost reductions:

- Work with minigrid developers, hardware suppliers, and other partners in the value chain to help harness the economies of scale and power of bulk purchasing.
- Create a larger, more reliable pipeline of projects to drive development of standardized and modular designs.
- Work with developers and the global supply chain to design and purchase minigrid-in-a-box systems that are the right size for particular communities.
- Determine when rapidly declining costs for alternative battery chemistries might make them more cost-effective for minigrids than lead-acid batteries, especially those with a longer cycle life such as lithium ion.

2. ENSURE THAT THE ELECTRICITY GENERATED IS FULLY UTILIZED THROUGH DEMAND STIMULATION AND OPTIMIZED LOAD MANAGEMENT.

Many existing minigrids suffer from an ironic problem—not enough demand, especially during the middle of the day when low-cost energy from solar panels peaks (see **Understanding Minigrid Costs**, page 17). There are several solutions to this problem:

Locate minigrids near productive uses of energy: Siting operations near grain mills, garment factories, hospitals, or a business district of shops ensures sufficient demand and revenues. One strategy, therefore, is to identify communities where such demand already exists. The typical current approach starts by using satellite imagery to spot rural areas that are dark at night, presumably because they are not connected to the grid. Then teams head out into the countryside, searching for communities with enough economic activity to justify building a minigrid.

But each of these steps presents challenges. For example, Nigeria's REA discovered that satellite imagery can be misleading where grid power is unreliable because even areas connected to the grid are often dark at night. And minigrid companies that work in East Africa report that they can drive around the countryside for weeks at a time without finding a village that offers sufficient demand for a minigrid.

There are a variety of ways to improve the efficiency of searching for suitable locations. For example, the Nigerian REA has developed a mobile application for a smartphone or tablet that enables rapid and inexpensive sourcing of data on possible sites. The app allows a field worker to visit a community and collect data on the numbers of households and people, schools, churches, and businesses (such as grain mills, welders, or hotels). The data then makes it possible to estimate the existing loads and the potential for additional loads.

Using this approach, the REA has so far identified over 100 promising sites for minigrid development in Nigeria, each with an average estimated peak demand of 100 kW–200 kW and enough existing businesses to support the minigrid investment.[17] Ideally, a site would have several existing commercial energy users, such as grain mills, that could serve as an "anchor" load. For example, in Obayantor in Nigeria's Edo State, the key customer for the solar minigrid built by Arnergy was a mill for grinding cassava and peppers that had previously used a big diesel-powered machine.

There are opportunities for greater grassroots involvement, helping to identify loads and sign up a critical mass of initial customers, similar to the US REA's approach in the mid-twentieth century. For example, a data-collection app could be made available directly to communities. This would enable village leaders to fill out a survey and send it in. They could consult with REA and learn from the app how a minigrid could lower their costs of energy or provide more opportunities for local businesses and for economic growth. As a result, there would be greater buy-in from the community—and a higher probability of full utilization—before the project even started. Sometimes the most effective strategy for finding promising sites is to show communities what is possible. Overall, a key goal is to switch from customer push (where companies try to find demand) to customer pull (where communities actively seek out a minigrid to meet the demand that already exists).

Find ways to create or stimulate demand: Although building supply is necessary, assuming that providing supply will generate demand fails to address the demand-side barriers end-users face. To ensure meaningful access to energy, end use needs to be considered a core part of electrification. This approach is sometimes referred to as "demand stimulation" or "stimulation of productive use." RMI's report *Closing the Circuit: Stimulating End-Use Demand for Rural Electrification* explores the opportunity presented by demand stimulation.[18]

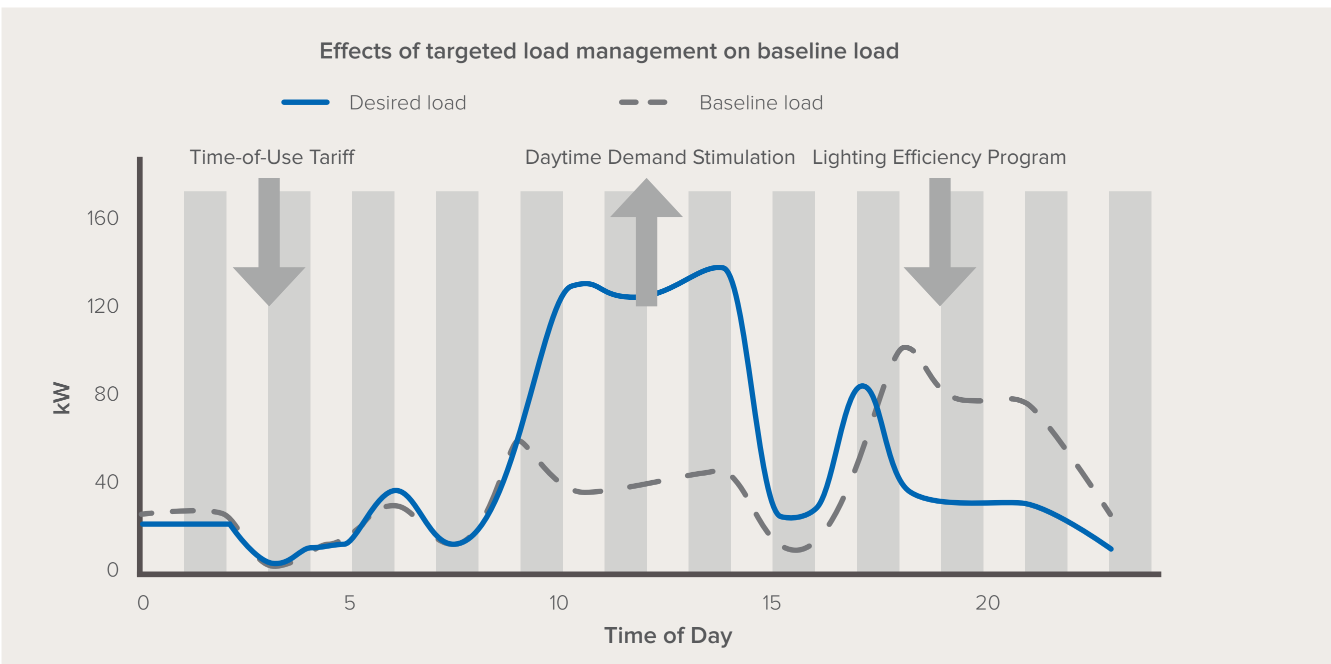
Some minigrid developers are already exploring options for stimulating demand in communities they serve. For example, in Nigeria, Green Village Electricity (GVE) has experimented with financing productive use equipment such as grinder motors. In the village of Bisanti, GVE has been able to increase utilization to 74% of peak capacity for its minigrid by providing loans for soft-start electric motors, and the company expects further adoption will raise that to 90%. And CrossBoundary Group, with funding from The Rockefeller Foundation, is looking at the potential benefits of financing energy efficient appliances for minigrid customers.

A minigrid company could also set up a new business that uses energy, or partner with another company to bring new business to a community, sometimes described as value-added services. This approach has been tested in Chanpatiya, India, where the availability of minigrid power made it possible to build a facility to purify water through reverse osmosis. Selling water provides a steady stream of income. Moreover, a load like a water purification system is flexible, so it can be ramped up and down to match the generation profile.

Proactively manage demand—especially flexible loads—to more fully utilize/absorb variable renewable generation. As the **Understanding Minigrid Costs** box on page 17 describes, unused capacity is very expensive, as is the fuel needed to run diesel backup generation—and the capital and operating costs of battery systems. It is vital, therefore, to find productive uses that can fully utilize peak solar power generation (usually in the afternoon) as well as flexible loads, such as pumps, water purifiers, or even cold storage that can be switched on or off to follow the generation profile. Minigrid companies also need to work to shift demand as possible from expensive morning or evening power to cheaper daytime solar power. Strategies include using efficient LEDs or fans or adjusting pricing to encourage customers to run equipment or appliances during the day. Our analysis shows that successfully finding, creating, and managing demand to ensure maximum utilization can lower LCOE for minigrid power by $0.08 per kWh. **Figure 6** shows the effect of this demand management.

FIGURE 6

BETTER MANAGING A MINIGRID'S LOAD PROFILE CAN INCREASE PROFITABILITY



Ideas for realizing this reduction include boosting financing for electricity-using equipment and businesses, and developing modular add-ons to minigrids that could inexpensively increase capacity as demand increases (thus making it possible to initially build a small minigrid with a lower risk of overcapacity). There may be opportunities for companies to specialize rather than this being solely the domain of minigrid developers. One company or organization with extensive local knowledge could specialize in finding sites, signing up customers, and working with businesses to manage demand, for instance, while another could build the minigrid, and still another could handle most of the operations and management (O&M) (see **Specialization in the Value Chain**, page 29).

3. FOCUS ON CUSTOMER ACQUISITION AND RELATIONSHIP MANAGEMENT.

As the previous section describes, strong community engagement is important in finding and surveying sites with sufficient demand and productive loads, signing up customers, and managing demand. However, working more closely with local communities provides additional gains. Not only can local people be trained for many jobs connected with minigrids but also communities can take over some of the management and even ownership roles. This better aligns incentives for finding loads, signing up new customers, security, siting, and improving collections. Some level of community ownership will also keep part of the profits in the local community, creating a virtuous cycle for further economic development and new electricity demand.

In the United States and Scandinavia, rural electrification was driven by rural farmers who joined together to form cooperatives that built and owned transmission and distribution lines, with the support of government loans. In Africa, creating such a cooperative ownership model for minigrids may require more outside assistance but promising precedents already exist.

In East Africa, for example, the nonprofit One Acre Fund was created to help smallholder farmers, who often struggle to grow enough food to feed their families. The organization provides high-quality seeds, fertilizer, and technical assistance on credit to farmers. Then it helps the farmers store and sell their crops. By providing information on markets and fluctuations, One Acre Fund enables farmers to sell at higher prices.

To make the model work as efficiently as possible, One Acre Fund uses a tablet-based system to enroll farmers and collect data remotely, and uses a flexible repayment approach with mobile money that allows farmers to pay back their loans in any amount throughout the loan term. The model has been so successful that membership has grown from its first group of 38 Kenyan farmers in 2006 to more than 400,000 farmers across six countries today, with a target of 1 million by 2020.

The same basic model can be extended beyond agriculture. In 2011, One Acre Fund began offering solar lanterns and, more recently, solar home systems. Because the organization has the trust of hundreds of thousands of farmers, as well as its proven mobile payment operations, it has rapidly become one of the largest sellers of such systems in Africa. Customers typically make an initial small payment and then a monthly payment for a few years until they own their systems.

In Nigeria, a company called Babban Gona has created a similar agriculture franchise model, helping some 40,000 smallholder farmers boost yields and profits.[19] A logical next step for both organizations is to move from seeds and fertilizer into agricultural processing as well, working with farmers to grind their own cassava and other crops, adding value and increasing revenues. That processing, of course, requires affordable and reliable power.

Another existing cooperative model in Africa is the Savings and Credit Cooperative Organization

(SACCO). A SACCO is owned, managed, and run by its members, and it provides a structure for the residents of a village to pool their savings for projects. There may be other options as well, such as the innovative German crowdfunding platform Bettervest, which recently funded a minigrid project at Gbamu Gbamu in Ogun State, Nigeria.[20] With the growth of other off-grid solar-oriented crowdfunding platforms such as Sweden-based TRINE, the potential is clear to raise funds cheaply from a large pool of small investors willing to accept risk for a good cause beyond what a traditional lender would accept for customers with no established credit or collateral.

The success of these existing cooperatives and community groups suggests that communities themselves could take full or partial ownership in minigrids (see **Community Ownership**). Even if that proves challenging, however, many opportunities for community engagement that will lower overall minigrid costs exist. These include partnering with existing trusted groups, from agricultural cooperatives to churches, to explain the benefits to communities and to sign up customers in advance—and perhaps involve the community in design, planning, and construction. As described in the previous section, community engagement is also key to creating and stimulating demand, understanding the potential productive loads and the willingness and ability to pay, and setting up easy payment mechanisms, such as mobile money. Our analysis shows that successful customer engagement will cut the cost of minigrid power by $0.06 per kWh.

We suggest pilot projects to explore community engagement options by working closely with REAs and developing a playbook for community activation that would enable a minigrid developer to both understand the needs of communities and increase community participation in the development.[21]

Community Ownership

It is rare for rural communities in the developing world to have the resources or creditworthiness to be able to finance their own minigrids. But it may be possible to explore community ownership using low-cost loans if foundations, development agencies, or governments are willing to accept disproportionate risk to test whether the model can work.

Such low-cost below-market financing was spectacularly successful during the US rural electrification, with total losses from defaults over the US REA's 43-year history of less than $50,000, out of more than $100 billion in loans (present value).[22]

Today, more than 900 consumer-owned, not-for-profit, electricity co-ops remain in the United States, spread over 47 states and with a combined value of almost $400 billion.[23] They are now interconnected with other utilities but could be considered minigrids when they first started. A board of locally elected representatives handles decision-making, and excess revenue beyond the cost of service is either reinvested or returned to customers.

There are also opportunities for partial community ownership, split with a company, with profits divided based on ownership to provide everyone a stake in success. Or minigrids could follow the solar lantern and home systems model, where customers pay monthly for a period of years, after which they own the capital equipment. Still another possibility is a franchise-type model.

4. CUT COSTS OF BUILDING AND OPERATING MINIGRIDS.

Most minigrids are currently constructed one at a time in remote locations. Building many minigrids in closely spaced clusters, however, is far quicker and more efficient.

The benefits are illustrated by an earlier example of Nayo Tech experience with Tungan Jika in Nigeria's Niger State. Once the minigrid was up and running, customers quickly saw the benefits of affordable, reliable power. So did members of 10 neighboring communities, all within a couple of kilometers of Tungan Jika. The leaders of those villages came to Nayo Tech and asked if the company could build minigrids for their communities as well.

Nayo Tech is now planning to create a ring of 10 new minigrids for these communities, and the company sees significant potential cost savings through this clustered approach. For one, the larger scale enables buying panels and components in bulk and, thus, at lower prices. Developing nearby projects allows additional economies of scale and cost sharing; for example, to install the original minigrid in Tungan Jika, Nayo Tech had to build a new bridge. Now, the same bridge provides access to the 10 other sites. The company even sees potential operational efficiencies, as the communities could eventually be linked to balance power across them.

Specialization in the Value Chain

There is no inherent reason one company or organization must undertake all the tasks needed to build a minigrid, from finding sites and signing up customers to designing the minigrid, buying the components, and building and operating the project. A more efficient model may be splitting up those functions.

Local companies or organizations such as the One Acre Fund could use their extensive existing trusted relationships with communities to find sites with sufficient demand and to sign up customers. Then, with clear knowledge of the size of the demand, they could order a minigrid from a major equipment supplier such as Schneider Electric or GE. These suppliers would have already designed standardized and modular minigrids in several sizes.

Once the supplier received the order, it would purchase the components and preassemble them at a central facility. Schneider Electric already has such an assembly plant for transformers in Nigeria, for instance. As minigrids scale up, the suppliers would be working on many projects at once, enabling them to save money by bulk purchasing and by achieving economies of scale in the preassembly.

Another company, perhaps an experienced minigrid developer such as PowerGen or Rubitec, could then install the minigrid, build the necessary distribution lines, and focus most of its attention on load management and demand stimulation. Alternatively, installation, operations, and maintenance might be handled by an energy service company (ESCO) or a telecommunication tower company such as OMC or IHS with existing logistics and scale procurement. Once the minigrids are built, companies could partner with a banking or telecommunications firm to collect payments. Or they could even turn day-to-day management and maintenance to a specialist in operations or to an organization or cooperative with ties to the community, thus bringing the value chain full circle.

With 10 projects instead of one, soft costs such as engineering, labor, site visits, signing up customers, setting up payment systems, and managing and maintaining the minigrid will also be much lower than for the Tungan Jika project. Just sending a representative from a company's headquarters to visit one distant site can require an overnight trip at a cost of hundreds of dollars. Nayo Tech estimates that being able to visit 11 minigrids in a single trip will dramatically cut the cost of site visits. Overall, the 10 new minigrids will cost 40% less than the original one.

This clustering approach can be extended far beyond 11 sites—in many areas, it is easy to imagine 100 or more minigrids separated by no more than two to three hours of travel distance. This setup would make it easier to form strategic partnerships to not only take advantage of economies of scale but also better tap into local knowledge and labor, increasing community engagement. We estimate that clusters can also lower land acquisition costs and reduce overhead costs by as much as 60%, especially when combined with integrated remote monitoring systems and webcams. Such monitoring systems can automatically tell minigrid owners when the diesel generator needs maintenance, for instance, or spot a drop in PV or battery performance that requires fixing. They are already used successfully by telecom companies to monitor far-flung wireless towers around the clock in Africa.

Another way to cut costs is to divide up the work among different companies or organizations, each of which specializes in a part of the value chain, and thus is more efficient (see **Specialization in the Value Chain**, page 29).

Overall, we calculate that building clusters of minigrids combined with streamlined project development, O&M, and remote monitoring will reduce the final cost of power by 8%, or $0.05 per kWh. Specific ideas for moving ahead to realize these savings include:

- Apply standardized systems with established reliability, preassembled to improve quality control and reduce field installation time
- Work with local partners that can build specialized experience for each region
- Develop remote monitoring systems to respond quickly or preventatively as maintenance issues arise and keep systems operating at top performance
- Partner with companies such as ESCOs or tower companies that can access scale purchasing with existing logistics networks
- Partner with companies that already have strong customer relations, an understanding of potential productive use loads that can drive economic development, and proven tools for assessing credit and reliable collections
- Train local talent and hire regional managers
- Collect and share limited data on operational performance

5. ENABLE LOW-COST FINANCING.

Most existing minigrid projects have been funded by grants, equity, or with greatly subsidized interest rates. Those sources of financing are crucial because commercial loan rates available for minigrids in sub-Saharan Africa are too high, at 15%–20%, for minigrids to get off the ground.[24] Increasing the availability and reducing the cost of capital for minigrid projects will be crucial for scaling a profitable business model. For example, lowering the interest rate from 20% to 5%, would cut the debt cost over the lifetime of a typical minigrid by nearly in half.

The **Developing an Investment Roadmap** section lays out a detailed pathway for moving from today's grant financing to low-cost commercial debt. In brief, the key is to increase lender comfort with minigrids by using grants to fund a few carefully designed and sited minigrid projects, then rigorously measuring their performance to prove the business model. This approach will open the door to concessional financing to support construction and operation of scores more minigrids. The success of these facilities, documented with hard data, would then attract venture capital and private equity investors and start the flow of low-cost commercial financing. Low-cost capital for new equipment would also enable electricity customers to buy the new appliances and other devices that would accelerate the demand for energy, reinforcing the positive cycle of investment and consumption. We calculate that reducing the cost of capital by just 4% can save $0.03 per kWh.

Four actions will enable this cost reduction:

- Standardize different parts of minigrid financing, including the supply chain, project finance, and consumer finance
- Grant funding for three to five projects that can prove strong customer demand and provide data on load growth over time and customer ability and willingness to pay
- Engage early with subsequent funding rounds to clarify necessary proof points to de-risk and unlock future funding
- Provide additional financing to buy appliances and productive services, thus helping customers increase demand and diversifying (and increasing) investor returns

6. REDUCE REGULATORY BARRIERS, COSTS, AND RISKS.

Today, regulatory and policy conditions often introduce significant risk into minigrid development and investment. There are many potential sources of risk, but they commonly present in four key ways. *Import duties, taxes,* and *customs delays* add cost and time to projects; inconsistent *tariff approval* processes leave the door open to delays and ultimately non-cost-reflective tariffs; lack of coordination with *government* or *central grid planning* can create conflicting plans; and unclear or inefficient *permitting processes* can stall development throughout the project life cycle. There are clear actions that governments can take to minimize these issues, which can both unlock additional investment and **reduce minigrid costs by $0.03 per kWh (5%).**

Import duties and uncertain customs delays are one example of minigrid development and investment risk. Importing a solar panel into Sierra Leone is tax exempt, for example, but inverters and other components can be charged with duties that are as high as 40%. Moreover, gray areas contribute to uncertainty. If an inverter is already wired up to solar panels, is it tax exempt or subject to import fees? Why should solar panels be exempt when the inverters necessary to make them useful for most appliances must pay full duty? Such questions and other problems can leave shipments tied up in ports, sometimes for months.

In addition, the fees mount up. Overall, customs duties, value-added tax (VAT), and local taxes can add almost 50% to the total hardware cost. These unexpected costs can quickly dissolve developer profit margins and make tariffs unaffordable for consumers.

Perhaps more challenging, rules for setting tariffs (the price customers will pay for a unit of electricity) present another set of risks and uncertainties. In some countries, minigrids are not allowed to charge more for electricity than the rates of the central grid—a major problem when the grid is heavily subsidized (see **A Note on Subsidy**). Just getting tariff approval can be a long, expensive process. And there are major uncertainties about when the central grid might arrive, and what happens then to the minigrid. In some cases, the grid tariff might undercut the prices for minigrid electricity, putting the minigrid out of business.

In other cases, minigrid owners are required by law to work with the central grid utility if grid power is available. In some cases, once connected to the main grid, minigrid owners may be required to sell to the utility. And it is not always clear if they will be treated fairly.

Many communities well-suited for minigrids are in areas where governments have announced plans for grid extension. Some of those plans, however, are clearly unrealistic. Minigrid developers are left to assess the risk of moving ahead at those sites, with the possibilities of either potential customers choosing to wait for the grid to arrive, or for the grid to actually arrive, reducing revenue.

Fortunately, several governments have made progress streamlining policies and regulations. For example, Nigeria and Tanzania no longer require tariff approval for minigrids under 100 kW in size (in peak power), and both countries have expedited the permitting processes. Companies and investors can build on these successes in working with other countries to reduce costly or daunting regulations and policies, such as import duties. Regulations will be tested and refined over time as the minigrid market matures.

Additional opportunities include waiving customs, duties, and VAT for all minigrid components (not just solar panels), reducing port delays, clarifying grid interconnection procedures, publishing grid extension plans, allowing reasonable tariffs, and reducing licensing and permitting requirements. We estimate that supportive regulation and policies can shave $0.03 per kWh off the LCOE for minigrid power.

A Note on Subsidy

Most conventional grids in sub-Saharan Africa are explicitly or implicitly subsidized by government; revenues collected are less than costs expended. Grids across the world, including those in fully developed countries, cross-subsidize their least profitable customers with revenue collected from their most profitable customers. While our analysis shows it is possible to provide electricity with a commercially viable minigrid model in communities with strong commercial activity in sub-Saharan Africa, serving the least profitable customers (who use very little electricity or require significant infrastructure to serve) will always require subsidization. Governments and development partners must therefore consider the role subsidy plays in ensuring the least profitable rural customers are served in rural electrification efforts regardless of the technology or system used.

04 DEVELOPING AN INVESTMENT ROADMAP

Image © RMI. A mill in a village near Woreta, east of Lake Tana, in Northern Ethiopia. Farmers from the region bring their maize and tef, the local staple, to be milled here using loud, polluting diesel-powered motors. The village is not electrified and fuel for the motors is carried 20km by donkey. This is one of 16 mills operating in a cluster on the edge of the village.

DEVELOPING AN INVESTMENT ROADMAP

Bringing affordable, reliable electricity to hundreds of millions of people across sub-Saharan Africa requires building enormous numbers of minigrids. For context, a similar effort to electrify rural areas in the United States required $110 billion (present value).[25]

This level of investment will not happen overnight, but can be accelerated by taking a strategic approach to project development. Together with key members of the investor community, we have developed a roadmap that includes the size and type of funding needed, as well as pathways for investment. Refined and validated through the recent minigrid design workshop and intensive consultations with experts, this roadmap charts a transition from today's grant-funded projects to impact and strategic investors with access to concessional debt, then to venture capital and blended finance, and finally to the much larger pools of capital from private equity and commercial debt that are needed to seize the multibillion-dollar market opportunity.

What is important is that this transition can happen quickly—and, in fact, is already beginning. One of the major conclusions from our convening work is that the roadmap itself can offer confidence to investors, showing a viable pathway for rapidly unlocking this new market. Using this roadmap, investors and developers coordinate around stage gates for how specific projects will deliver the reliable data and proof needed to de-risk minigrids as an investment and unlock subsequent rounds of funding. Each round of projects will lead to the next, much larger round, unlocking each subsequent source of capital (see **Figure 7,** page 35).

Image © RMI. MI staff Sachi Garber and James Sherwood during a minigrid site visit in Benin

FIGURE 7
A ROADMAP FOR INCREASING MINIGRID INVESTMENT

	Grant funding and government programs	Impact and angel investors with high-risk concessional financing	Venture capital investors with blended finance	Private equity and commercial debt
ILLUSTRATIVE EXAMPLES	Global Environment Facility, Rockefeller Foundation	Equity from impact fund, debt from government. aggregator with near-zero interest rate	Omidyar, CRE, or GE VC	Equity from Helios, AIM, or LGT, with debt from Stanbic or Standard Chartered
PROJECT ROI	NA	0%–10%	10%–15%	15%–20%+, with portfolio-based minimum ROI
PROOF POINTS, DATA, AND CAPABILITIES NEEDED TO ACCESS THIS FUNDING	• Technical reliability and quality of service • Show social/ economic development benefits	• Data/case studies for overall market showing latent demand for electricity, growing demand over time, as well as new customer ability/ willingness to pay • Demonstrated cost reduction, both hard and soft • Companies with operational track record and data • Companies beginning to develop IP, supply chains, and some local content	• Low-cost customer acquisition and site selection • Emerging structures to standardize financing • Market with high growth potential • Companies with clear business model and scaling strategy • Companies with institutional/ management structures and strong leadership teams • Exit strategy for investors • Hardware cost reduced with scale and a standardized solution	• Clearly established and growing minigrid market • Standard KPIs and financing structures • Credible equity portfolio and ability to secure debt • Companies with strong project pipeline, scaling partners, or anchor customers • A portfolio approach for project financing • Option to refinance some early projects with existing revenue to get started
# OF PROJECTS AND AMOUNT OF FUNDING REQUIRED	3–10 projects, $3–$10M grant funding	20–30 projects, $10–$15M grant as part of $30M min portfolio for concessional finance	Hundreds of projects for >$50M	Thousands of projects for >$500M
SUPPORTING ACTIVITIES AND COLLABORATION	• Case studies showing customer demand/payment • Clear government policies and duties	• Financing network • Outreach/ engagement with next round of funders • Industry association	• Finance consortium/ blended capital	• Regulatory certainty

The first step of this roadmap is critical—moving from grant funding to the first round of impact/angel investors along with concessional debt. The projects would rigorously focus on proving that customer demand exists and the communities are able and willing to pay enough to make the business model commercially viable. That data would then give larger investors the confidence to enter the market.

Following this roadmap, it is possible to line up subsequent funding rounds through the program (perhaps as a steering committee preceding programs), and our work suggests that strategic investors, venture capital, private equity, and commercial debt could all enter within three to five years.

These results are encouraging and helping to convince the industry that the time to act is now, working with communities, governments, and the development community. Indeed, our analysis shows that investors and companies that act aggressively on minigrids will gain important first-mover advantages and economies of scale that later entrants will find difficult to match. The winners will be those that start now, learn quickly, break down barriers, and develop the best sites and business opportunities.

05 CONCLUSION

Image Courtesy: DFID. Ramadhan Stands Among His Cabbages at His Home in Rugina, Rwanda

CONCLUSION

Our detailed analysis, supported by extensive consultations with companies, foundations, development agencies, and governments, shows that a profitable and scalable minigrid business model is possible over the next several years, bringing transformative benefits to hundreds of millions of people across Africa and beyond. The keys to getting there are:

- Understanding what is possible and where to focus efforts for cost reduction
- Providing a roadmap that can be used to engage up front with investors, accelerating progress and increasing confidence and investment in the minigrid business model
- Focusing on private-sector innovation and driving down costs to reach a business model that is profitable and scalable
- Taking a whole-system approach starting with the six opportunity areas discussed in section three, **Solutions: Cost-Reduction Pathways for Rural Minigrids**
- Designing programs to deliver specific outcomes required for de-risking the market
- Unlocking subsequent rounds of funding and engaging subsequent funders early to understand what proof points are needed and to set stage gates to guide progress
- Learning lessons from historic electrification efforts, such as the importance of standardization, low-cost finance, and community involvement
- Exploring opportunities for community engagement to maximize local benefits and align incentives for finding daytime productive loads, signing up customers, and managing cost for siting, security, and collections

The stakes are enormous—there is not only a huge business and economic development opportunity but also a chance to make a profound difference in the lives of hundreds of millions of people. Affordable, reliable electricity will prevent countless cases of disease by refrigerating lifesaving vaccines and drugs. It will reduce hunger and boost profits for local farmers and fisherman by reducing the spoilage of meat, milk, and fish, and by increasing agricultural productivity. It will replace the backbreaking labor of carrying water and gathering wood, enable children to study late into the evening, and cut pollution and poverty. It will start a virtuous cycle of economic growth as the combination of reliable power and higher rural incomes unleashes entrepreneurs to build new businesses. And it will offer communities the chance to help manage, perhaps even own, their own minigrids.

Bringing a better, electrified future to many millions of people in the developing world while creating a new once-in-a-generation business is an opportunity we cannot afford to miss.

APPENDIX: ANALYSIS METHODOLOGY AND ASSUMPTIONS

Image © RMI. RMI staff Ebun Ayandele and Andrew Allee during a site visit in Gbamu, Nigeria.

APPENDIX: ANALYSIS METHODOLOGY AND ASSUMPTIONS

We have visited and evaluated dozens of projects and potential sites in Nigeria, Uganda, Rwanda, Kenya, Sierra Leone, and India. What we have found is that although the minigrids are technically successful, few have demonstrated a viable and scalable business, with sufficient return on capital to draw in the really large investments needed to scale up the approach. Many have not lived up to expectations because of such problems as initial high capital costs or insufficient electricity demand. Some minigrids must rely on customers willing to pay more than $2.00 per kWh to get the return they need. Surprisingly, a current major problem is the perception that not enough demand for power exists to justify major investments.

We held a three-and-a-half day minigrid design workshop, or charrette, in Nigeria with more than 60 leaders from industry, development agencies, foundations, and governments in early March 2018 to discuss issues and opportunities. Our previous experience led to a minigrid costing model that was tested and improved upon at the design workshop. It is described in detail below.

What the model does

We designed a model to answer the question: how much can the cost of minigrids be reduced by 2020? Our model estimates the cost for a best-in-class minigrid today. Using the six opportunities for cost reduction explained in the body of this report, we then estimate how much costs can be reduced in each opportunity by 2020.

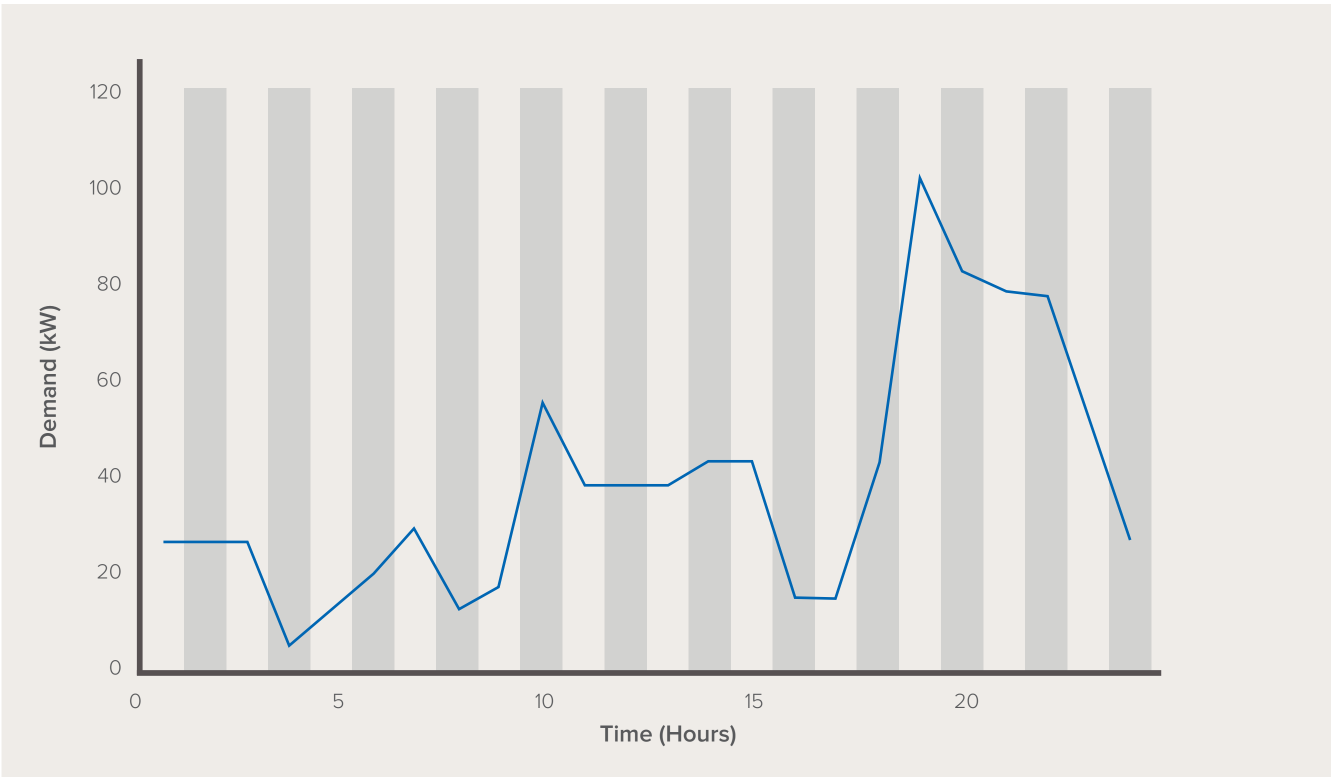
Model structure

All costs are calculated with a financial model built in Excel. Minigrid systems that feed into the financial model are sized in HOMER Energy software. Two minigrid systems are modeled, the baseline case and the load managed case. In the baseline case, a load curve for the Iju community is used as the demand input. Baseline capital expenditure costs are the cost inputs. Solar resources are based on the location of the Iju community. In the load-managed case, the demand curve reflects the load management interventions. Capital expenditure costs reflect the hardware cost-reduction opportunities. The location remains the same.

Baseline model: Today's minigrid costs

Our model considers a solar-battery-diesel hybrid system. The system is sized for Iju (Ilasa) a 160-kW peak community in Ogun State, Nigeria. The estimated community load is shown in **Figure 8** on page 41. This site is being developed by a small minigrid developer as part of a portfolio of 15 sites per year.

FIGURE 8
LOAD PROFILE FOR IJU (ILASA), OGUN STATE, NIGERIA



Developing, building, and commissioning a minigrid takes many steps from start to finish, each of which adds to the final cost of the minigrid. We call the accumulated costs broken into categories the **minigrid cost stack**. Our baseline cost stack is defined as best-in-class, current costs within each cost category from development to commissioning. The developer incurs different costs at different times and at different frequencies across the lifespan of a minigrid, which we assume to be 20 years. Some costs are up-front costs, which occur once at the start of the minigrid project. Other costs occur periodically throughout the life of the minigrid; these costs are ongoing costs. **Figure 9** on page 42 shows the typical timeline of a minigrid project.[26]

FIGURE 9
MINIGRID PROJECT TIMELINE

Because minigrid costs occur irregularly, we use LCOE to compare across cost categories and to size the different categories of the minigrid cost stack. LCOE is the measure of lifetime costs divided by energy production.[27] **Equation 1** shows how LCOE is calculated.

Our model assumes the minigrid developer is financing the project with a debt and equity blend with a weighted average cost of capital of 13%.

Up-front soft costs

Up-front soft costs include all the costs of developing the minigrid before any steel goes in the ground. The activities that incur these costs are customer engagement, engineering and design, environmental impact assessment (EIA), due diligence (DD), legal, duties and fees, site preparation, project delays, and land acquisition.

Customer engagement

Customer engagement encompasses the customer-facing activities that a minigrid requires to operate. These include site selection, customer acquisition, and customer retention. Site selection is the process of selecting sites to build a minigrid. We assume our baseline minigrid company operates out of a major city with sites spread across the country where they operate. As such, we calculate the cost of site selection as travel time to and stays in sites spread across a wide area. Sites are selected in teams of two engineers and four laborers that can visit three sites per day based out of a hotel near their points of interest. They stay at each hotel for five days. We assume teams have a 20% success rate finding a site, so finding 15 sites takes 75 visits. **Equation 2** on page 44 shows the calculation for site selection.

EQUATION 1

LCOE CALCULATION

i. $LCOE = \frac{C_{ann'tot}}{E_{served}}$

ii. $C_{ann'tot}$ = *Annualized cost of producing energy* $[\frac{\$}{y}]$

iii. E_{served} = *Total electrical load served* $[\frac{kWh}{y}]$

iv. *HOMER Energy, a leading minigrid software provider, describes LCOE calculation in more detail*[28]

EQUATION 2

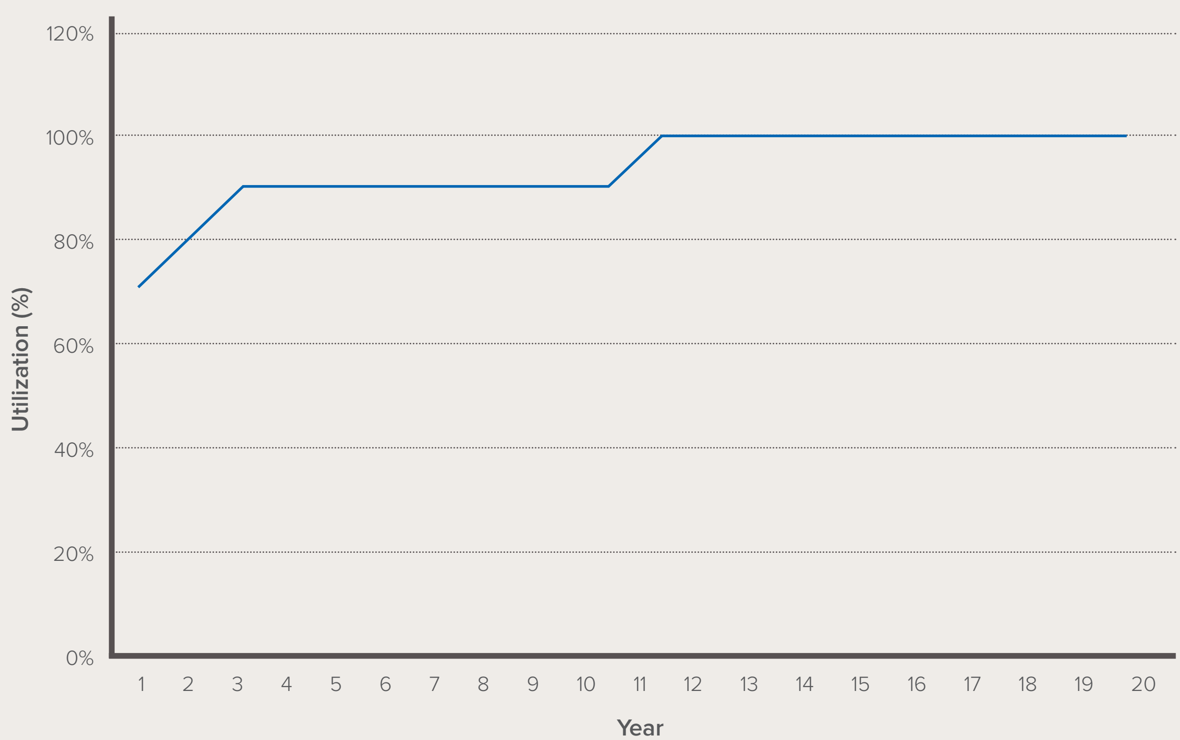
SITE SELECTION

$$\textit{Site selection} = \frac{\textit{Labor cost} + \textit{Engineer cost} + \textit{Fuel cost} + \textit{Flight cost} + \textit{Accomodation cost}}{\textit{Number of sites}}$$

Customer acquisition and retention determine the capacity utilization of the minigrid, which is the ratio of amount of kilowatt-hours sold to the amount the minigrid is expected to sell. We define losses as the cost of underutilizing the system. In the baseline model, the system is underutilized for the first 10 years. **Figure 10** shows the utilization curve we assume in the baseline model. Losses have their own category within the cost stack.

FIGURE 10

MINIGRID UTILIZATION OVER 20 YEARS IN BASELINE CASE



Engineering and design

Engineering and design costs represent the time spent creating the engineering design of the individual minigrid components, integrating the system to bring all the components together, and creating the financial model for the project. We model this as the product of labor rates and time for two consultants and six engineers working for 1.5 months.

EIA, DD, and legal support

EIA, DD, and legal support are modeled as a lump payment to an outside contractor. This cost is based on similar costs in industry.

Duties and fees

Duties and fees are costs incurred in addition to the capital cost of minigrid equipment. Typically, these costs are set by policy that differs between countries. In Nigeria, for example, duties on solar panels are waived, but there is a 25% tariff on batteries made up of a 20% import duty and a 5% value-added tax. Because of the variability in duties and fees across countries, we assume a flat tariff of 25%.

Site preparation activities

Site preparation activities are those performed to make the minigrid site ready for construction. We include in this category the cost of aggregating equipment at port and trucking it to the site. In the baseline case, we assume equipment does not arrive together and is expensive to warehouse at the port, so multiple trips are made. The calculation of this cost category is shown in **Equation 3**.

Project delays

Project delays are costs incurred by the minigrid developer as they wait to commission the minigrid. Developers are frequently delayed by disputes at the port regarding customs, duties, and fees. Port officials will refuse to release equipment to the developer until disputes are resolved. Developers incur loan repayment costs from stranded equipment. Land acquisition costs vary widely. Our model assumes land costs consistent with those seen in other minigrid projects. We model project delay costs based on these loan repayments (see **Equation 4**, page 46).

EQUATION 3
SITE PREPARATION

$$\textit{Site preparation} = \frac{\textit{Truck fuel cost} + \textit{Truck rental cost} + \textit{Labor cost}}{\textit{Number of sites}}$$

EQUATION 4
THE COST OF PROJECT DELAYS

$$\text{Project delays} = \text{Payment (PMT)(Interest rate, loan tenure, stranded assets)} \times \frac{\text{Days stranded}}{365}$$

Capital expenditure costs

To build a minigrid, the minigrid developer makes an up-front purchase of power production and distribution and metering infrastructure. The individual components purchased in our minigrid model are shown in **Table 1** on page 47.

Capital costs for the baseline cost stack were first estimated from the bottom up using market prices for various components; for example, the per-watt price of a solar module was provided by subject matter experts. To estimate the total cost to install the solar portion of the minigrid, we then combined the module cost with the inverter, racking, foundation, and other solar component costs to estimate how much a watt of solar might cost in the United States, because it is a known market where we can be confident about prices. We then adjust how prices might change in sub-Saharan Africa with guidance from subject matter experts. Capital costs for the other power production elements and distribution and metering infrastructure were similarly built up using current costs for components. See **Table 1** on page 47 for a list of component cost assumptions.

Final costs take into account the equipment's lifetime and necessary replacements, as shown in **Table 2** on page 48.

TABLE 1
HARDWARE COMPONENT COST ASSUMPTIONS

	US/EU	SUB-SAHARAN AFRICA (SSA)*	2020 TARGET	NOTES
PV MODULES	$0.42/W	$0.58/W	$0.30/W**	All solar component prices based on Shine*** cost modeling adjusted to expected SSA prices. Benchmarked against current SSA minigrid developer costs. All 2020 costs include BAU global market cost trends
RACKING	$0.11/W	$0.15/W	$0.09/W	Current: higher material cost 2020: reduction through a low-cost, power field-type solution, or preassembly, or local manufacturing
PV BALANCE OF SYSTEM (BOS)	$0.05/W	$0.08/W	$0.064/W**	Includes BOS, AC Station, Comms/Monitoring system
BATTERY STORAGE	$145/kWh	$175/kWh	$158/kWh	Lead-acid; 5% year-over-year reduction. Li-ion is an interesting alternative, but not included here
INVERTERS	$0.07/W	$0.12/W	$0.06/W**	Current: 50 to 100 kW units at $0.07/W AC, includes $0.05/kWh for shipping 2020: includes 2/3 reduction through reduced clipping
BATTERY INVERTER	NA	$0.18/W	$0.13/W**	Based on SMA/Schneider off-grid solutions and local minigrids
BATTERY BOS	$0.01/W	$0.01/W	$0.01/W**	Includes racking, rack management, and other BOS
DISTRIBUTION	$20,000/km	$15,475/km	$15,475/km	Assuming LV distribution (1 and 3 phase), panelboards, and poles
1 PHASE CONNECT/ METER	$140	$140	$56	Per connection 2020: assume a load limiter at 1/3 cost
COM CONNECT/ METER	$335	$335	$268	Per connection
ADDITIONAL SAVINGS FROM STANDARDIZATION	NA	NA	20%	Hardware supplier spends less time on sales and engineering plus can accept lower margin for package sale at higher sales volume

*Not including duty, installation, or transportation to site.
** Assume 20% cost reduction through bulk purchasing while assembling standardized solution.
***Shine leverages economies of scale, standardized system design, innovative BM, and other levers to lower the cost of community-scale solar.

TABLE 2
REPLACEMENT COST ASSUMPTIONS

REPLACEMENT COSTS	LIFE SPAN (YEARS)
GENERATOR REPLACEMENT	8
SOLAR INVERTER	25
BATTERY (LEAD-ACID)	5
SOLAR 2020	25
BATTERY 2020 (LEAD-ACID)	5
DISTRIBUTION & METERING	25

Installation costs

Installation costs are a measure of the time and labor costs to install individual components. For example, diesel installation costs are the estimated time to build the housing and install the generator. Some of the project engineers' time is also allocated to supervising installation. Installation cost formulas for individual components are captured in **Table 3** on page 49.

TABLE 3
INSTALLATION COST ASSUMPTIONS

	SSA	2020 TARGET*	NOTES
DIESEL INSTALL	$0.008/W	$0.008/W	All install costs include local labor costs plus engineers allocated to project to design, install, and supervise three laborers for 20 days at $10 per day to install a generator and housing 2020: Diesel generator does not come included in standard solution
SOLAR INSTALL	$0.047/W	$0.08/W	SSA costs based on Shine US cost calculations for a standardized system adjusted by ratio of Nigerian wage to US wage
STORAGE INSTALL	$0.02/W	$0.003/W	Current: Assumes construction of racking and housing using three engineers and five laborers for 30 days at $50 per day, and a 300 kWh battery 2020: Assumes five laborers hook batteries to standard solution in five days
DISTRIBUTION INSTALL	$1,500/km	$1,500/km	Current and 2020: Team to install poles every 50 meters, 60 minutes per pole, five laborers at $20 per day plus a truck at $500 per day
CONNECTIONS AND METERS INSTALL	$0.003/W	$0.003/W	40 minutes per install, one junior engineer at $25/day; no change with standardized system

*Lowered installation cost due to a containerized, standardized system.

ONGOING COSTS

Overhead costs

Overhead costs reflect the costs of operating a minigrid company, outside of project-specific costs. The minigrid company that we model in the baseline scenario is a small company operating 15 sites. Overhead costs reflect the staff, infrastructure, and operating costs reflective of a small company. Costs are spread across all operating sites. **Table 4** on page 50 reflects the overhead costs assumed in the baseline scenario. Engineering costs are calculated separately in install, design, operations and management (O&M), and logistics costs.

TABLE 4

OVERHEAD COST ASSUMPTIONS

STAFFING COST	Management	$18,250/person
	Bookkeeping	$9,125/person
	Logistics	$3,650/person
	Executive	$50,000/exec
EQUIPMENT	Vehicles	3 Vehicles
	Avg. Vehicle Cost	$20,000
	Office Lease	$1,000/month

Operating costs

Operating costs are the reoccurring costs of operating an individual minigrid project. We model the costs for staff on-site, including three on-site staff for collections and local operations management and two guards to keep an eye on the site for 24 hours per day. We also account for the travel and salary of engineers to make routine trips to maintain equipment throughout the year.

Fuel costs

In the model, we set fuel price at $0.70 per liter (L) for diesel. We determine the unit cost of diesel fuel by the pump price plus the cost of logistics of fuel delivery. We assume $0.60 per L for diesel based on fluctuations of fuel price between $0.50 per L and $0.70 per L.

The cost of fuel logistics is a function of storage and transportation. We assume the site can store up to two weeks of fuel, so fuel is delivered between two and three times per week. Labor (driver and guards), transport costs, and truck rental costs add $0.10 per L to the price of diesel.

Fuel is an ongoing variable cost for the minigrid. Fuel cost is the product of the price of diesel and the number of liters consumed in a year. Diesel consumption is an output of the HOMER model.

Comparing minigrid costs

Because the minigrid market is fairly nascent across sub-Saharan Africa and costs vary across countries, we compare our bottom-up calculations for our baseline model to data collected from several minigrid companies in Nigeria and other data collected across sub-Saharan Africa. Minigrid company data is collected under nondisclosure agreements with Rubitec, Nayo Tech, VPS Energy, and GVE Partners Ltd. Other cross-sub-Saharan Africa data comes from the German Corporation for International Cooperation, Smart Power for Rural Development, and the International Renewable Energy Agency.

Cost-reduction opportunities

Within each category of today's minigrid cost stack, there is opportunity for cost reduction through a variety of means. Our model follows the cost-reduction logic explained earlier in this report, although other means of cost reduction exist. Our logic breaks the minigrid cost stack into six potential cost-reduction opportunities. The model is designed to test how each cost-reduction opportunity affects the LCOE for an installed and operating minigrid. The model does so by answering a series of questions related to the cost-reduction opportunities: Can costs be lowered: through hardware cost reductions? load management? customer engagement? more efficient project development, O&M, and overhead? financing? policy mechanisms?

How can hardware costs be reduced?

The hardware opportunity accounts for the capital costs to buy assets, labor costs to install assets, and replacement costs for assets over time. Our model estimates cost reduction by 2020 in three ways: business-as-usual (BAU) cost reductions, reductions from bulk purchasing equipment, and reductions from a standardized minigrid product. BAU cost reductions and bulk purchasing primarily affect the capital cost of equipment and its replacement costs. We estimate BAU cost reductions as a straight-line, year-on-year reduction based on current trends and expert input. **Table 5** details our yearly reduction assumptions.

Bulk purchasing cost reductions are based on a percentage reduction in price gained through the volume of purchase from a supplier. Subject matter experts at suppliers provided guidance on the amount of reductions possible. Standardized design allows us to assume a greater volume of purchasing, expanding the cost reduction available to us. We assume bulk purchasing reduces hardware costs by 20%.

TABLE 5
TABLE OF REDUCTION ASSUMPTIONS

Initial analysis suggests the cost of minigrid service can be reduced by more than 60% from $0.60/kWh to near $0.20/kWh by 2020 by addressing six key areas:

COST-REDUCTION AREA	$/KWH SAVED	% OF $0.60/KWH
1. REDUCED HARDWARE COST	$0.11/kWh	18%
2. EFFICIENT LOAD MANAGEMENT	$0.08/kWh	13%
3. EFFECTIVE CUSTOMER ENGAGEMENT	$0.06/kWh	10%
4. EFFICIENT PROJECT DEVELOPMENT AND O&M	$0.05/kWh	8%
5. AFFORDABLE FINANCING AVAILABLE	$0.03/kWh	5%
6. SUPPORTIVE AND ENABLING POLICY	$0.03/kWh	5%

Standardized design offers capital cost savings through reductions in foundation and racking costs. Foundation and racking costs are reduced 25% using a proprietary solution designed by Powerfield. However, standardized design primarily offers cost reductions in the hardware opportunity through installation costs. We assume most solar and battery components, besides panels, will be shipped in a containerized solution, practically eliminating installation cost.

How can load management reduce costs?

We hypothesized, and our experience has shown, that changing the load shape of a minigrid site before or during operation can have a significant impact on the cost to build and operate the minigrid. The load shape is changed through load management. Load management is applying interventions through technologies or programs that change when and how much energy customers of different types consume. For example, one type of load management is energy efficiency, which reduces the energy consumed by an appliance.

In our model, we test three load management interventions. These are a time-of-use (TOU) tariff, daytime demand stimulation, and an energy efficiency program. We model the TOU tariff as a shift of 10% of nighttime loads—those loads that occur between 0:00 to 06:00 and between 17:00 to 24:00—to the daytime—from 06:00 to 17:00. This shift mimics the behavior change anticipated by a minigrid developer implementing a well-designed TOU tariff. Daytime demand stimulation is modeled as a 200% increase in daytime commercial load. The modeled increase represents the adoption of productive use and commercial appliance by daytime users in the community. A minigrid developer would encourage this adoption through a mechanism such as a commercial lending program.

Energy efficiency is modeled as a 50% reduction in nighttime load between 18:00 and 24:00. This reduction is representative of a lighting swap (incandescent to LEDs) and a fan replacement program. We modeled the cost reduction of load management by applying load interventions individually, and then as a package. The final model reflects the full package of interventions because it provides the greatest cost reduction.

Many other forms of load management exist, including different tariff designs, various demand stimulation programs, and many kinds of efficiency. However, we test what we deem to be simple and impactful interventions.

Cost reductions from load management come from the change in hardware configuration that is made possible by the new load shape that exists after the interventions have been put in place. New hardware configurations are modeled in HOMER Energy software.

How can customer engagement lower costs?

We assume customer engagement allows for two kinds of cost-reduction opportunities. First, the costs of the load management program are tied with customer engagement so that half of load management savings are apportioned to the customer engagement opportunity. Second, better customer engagement increases customer acquisition and customer retention with the overall effect of increasing capacity utilization of the system.

We assume better customer engagement happens through an unstructured supplementary service data platform that allows for mobile payment and customer feedback. Our model incorporates the cost for designing, testing, and deploying this system to customers.[29]

How can O&M, project development, and overhead costs be lowered?

Standardized systems play a primary role in this cost-reduction opportunity. Standardized systems reduce project development and O&M costs. Project development costs are reduced at the engineering design stage, during site preparation, and during port delays. Our model assumes fewer engineers need less time to design the system because they are familiar with a simpler design. During site preparation, fewer truckloads need to be delivered to each site. Finally, port delays are reduced because port authorities are more familiar with the minigrid company's systems. O&M costs are reduced because staff are familiar with one system type and fewer staff, especially engineers, are needed for maintenance.

Further savings in this category are provided by clustering sites. A minigrid developer can deliberately cluster multiple sites within close proximity of each other. Clustering sites saves on project development and O&M. Project development costs are lowered during site selection, customer acquisition, and site preparation. Site selection and customer acquisition costs are lowered because the close proximity of sites means less is spent on travel to and between potential sites. Site preparation requires fewer trips, as clustered sites are daisy-chained together.

O&M costs are reduced because multiple sites within a cluster can be serviced by the same technician, and, relatedly, the costs for routine checks by engineers is reduced. Similarly, one customer sales representative can serve multiple sites. Furthermore, a minigrid company can partner with an actor familiar with the local area in a cluster. Partners decrease the cost of site selection by increasing the likelihood of finding suitable sites.

Operating at scale is a further opportunity within this bucket that reduces overhead cost. Our model assumes a minigrid company operating 100 sites. This setup spreads overhead costs over many more sites—a cost reduction that would not be available to a small minigrid company.

How can financing lower costs?

Financing costs can be lowered through a more favorable debt and equity blend. We model this opportunity as a weighted average cost of capital of 9%.

How can policy lower costs?

Policy can enable lower costs for minigrids by creating an enabling environment to make business easier and lowering exogenous costs the government might place on goods. We model this opportunity by removing port delays and lowering duties and fees to zero.

ENDNOTES

ENDNOTES

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