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TECHNICAL REPORT 013/18

MINI GRIDS AND THE ARRIVAL OF THE MAIN GRID: LESSONS FROM CAMBODIA, SRI LANKA, AND INDONESIA

ESMAP MISSION

The Energy Sector Management Assistance Program (ESMAP) is a global knowledge and technical assistance program administered by the World Bank. It provides analytical and advisory services to low- and middle-income countries to increase their know-how and institutional capacity to achieve environmentally sustainable energy solutions for poverty reduction and economic growth. ESMAP is funded by Australia, Austria, Denmark, the European Commission, Finland, France, Germany, Iceland, Italy, Japan, Lithuania, Luxembourg, the Netherlands, Norway, The Rockefeller Foundation, Sweden, Switzerland, and the United Kingdom, as well as the World Bank.

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PREFACE

About 1 billion people in the world lack access to electricity. Although the number has been steadily declining, the current speed of progress is too slow to meet the target of universal electrification by 2030 (Sustainable Development Goal 7). By 2030, 674 million people are projected to remain unelectrified.

A sizable portion of this gap can be attributed to lack of financing. Current commitments are estimated at less than half of the $52 billion a year needed to achieve universal access by 2030.

Another reason for the gap is that electrification programs have traditionally focused on extending the national grid. Doing so is often prohibitively expensive in remote settlements and areas with low population densities and low demand for electricity. Developing electrification models that complement grid extension is therefore critical.

Mini grids and off-grid systems are two practical complementary approaches to grid extension. Recent technological breakthroughs, the emergence of innovative business models, and enabling regulations and policies have made mini grids and off-grid systems affordable, scalable options for expanding electricity services. Mini grids are expected to contribute significantly to electrification efforts. The International Energy Agency estimates that they could provide access to electricity to more than 440 million currently unserved people by 2030.

Mini grids range significantly in size, from systems that provide electricity to just a few customers in a remote settlement to systems that bring power to hundreds of thousands of customers (usually groups of households, businesses, or public institutions) in a town or city. Some mini grids are connected to the main grid. When they are, they should have the ability to "island" (separate) their operations from the electrical system of the main grid.

Mini grids have existed for more than a century. In many of today's medium- and high-income countries—including Brazil, China, Italy, Spain, Sweden, the United Kingdom, and the United States—they were often the starting point of electrification. As those economies grew, these first-generation mini grids were merged into expanding national grids.

Today, mini grids are used largely in low-income countries in Africa and Asia. These second-generation mini grids are typically built to provide access in areas that have not been reached by the main grid or whose costs of a grid-based connection are prohibitive. Local communities and entrepreneurs generally run them, using mini hydropower and diesel generation technologies. With the arrival of the main grid, the mini grids usually go out of existence or transform themselves into small power producers or small power distributors.

Recently, a third generation of mini grids has emerged. These systems use modular generating technologies, generally solar photovoltaics. They have storage and backup systems; state-of-the-art control systems; and smart, prepay meters. Large international electrical equipment supply companies have developed standardized mini grid generation systems that can be deployed quickly. These firms are expected to build hundreds or thousands of installations using their proprietary technologies, achieving cost-reducing economies of scale that were not available earlier.

The rollout of these systems also benefits from new regulatory frameworks. These light-handed regulations are intended to streamline approval processes and offer more certainty about what happens to mini grids after the main grid arrives.

These changes are encouraging. But gaps in policies and regulations, the lack of long-term financing, and the limited exchange of the latest developments and experiences still constrain the large-scale deployment of mini grids.

To help address these issues, in 2015 the World Bank Group's Energy Sector Management Assistance Program (ESMAP) established the Global Facility on Mini Grids (GFMG). The GFMG helps mainstream mini grids into World Bank lending projects and national electrification programs and supports the development and dissemination of knowledge and learning on mini grids.

Since its launch, the GFMG has supported the World Bank's mini grid portfolio, which spans 28 countries and consists of 25 active and 7 pipeline projects with mini grid investment components. These projects are set to enable 2,500 mini grids, bringing electricity to more than 5 million people by 2025. The portfolio represents more than $500 million of World Bank funds and will mobilize an additional $1 billion in government, private-sector, and donor funding for mini grids in client countries over the next six years.

Examples of this work in Africa are the flagship "piloting at scale" projects in Kenya and Nigeria. The Bank's provision of $190 million in International Development Association funds for mini grids ($40 million to Kenya and $150 million to Nigeria) is expected to "crowd in" more than $230 million in private-sector investment. The GFMG also played an important role in creating the Africa Mini Grid Developers Association (AMDA), the first such association in Africa to provide a common platform for advancing the interests of mini grid developers in achieving universal access to electricity.

The GFMG also supports knowledge development to reduce the cost of energy delivery by solar hybrid mini grids to $0.30/kilowatt-hour by 2020, $0.25/kilowatt-hour by 2025, $0.20/kilowatt-hour by 2030, improve the viability of service providers, and advance the pace of deployment. It supports the spurring of demand, effective regulation, access to finance and technology, costing, geospatial-based portfolio planning, community engagement, involvement of the local and global private sectors, and a wide range of knowledge products to distill replicable lessons learned from past and ongoing activities.

This report is part of GFMG's knowledge development activities. Other activities have included comprehensive surveys of mini grid operators in Cambodia, Myanmar, Nepal, and Tanzania; support to Haiti, Kenya, Myanmar, Nigeria, Rwanda, and Tanzania to develop regulations or national strategies that make investing in mini grids attractive to private-sector developers; guidance on geospatial portfolio planning in Kenya and Nigeria to make detailed market intelligence available to the private sector (resulting in significant cost reductions in preparation); and assistance in the preparation of prefeasibility studies and business plans in Ghana, Liberia, and Niger.

To share and exchange the latest developments, the GFMG cohosts learning events. Events in Kenya, Myanmar, Nigeria, and Tanzania saw a doubling of attendees at every occasion, with more than 600 participants taking part in the most recent Action Learning conference, held in Abuja in December 2017. These events draw representatives from key stakeholders across the industry's value chain and serve as a platform for forging partnerships and sharing strategic insights from the World Bank's portfolio and frontier knowledge.

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ABBREVIATIONS

CEB	Ceylon Electricity Board
CR	Cambodian riel
CREE	Community Rural Electrification Entity
DFCC	Development Finance Corporation of Ceylon
EAC	Electricity Authority of Cambodia
ECS	Electricity Consumer Society
EdC	Electricité du Cambodge
ESD	Energy Services Delivery
ESMAP	Energy Sector Management Assistance Program
FECS	Federation of Electricity Consumer Societies
GFMG	Global Facility on Mini Grids
GWh	gigawatt
KPLC	Kenya Power and Lighting Company
kV	kilovolt
kW	kilowatt
kWh	kilowatt hour
LV	low voltage
MW	megawatt
NEA	Nepal Electricity Authority
NERC	Nigerian Electricity Regulatory Commission
NGO	nongovernmental organization
OECD	Organisation for Economic Co-operation and Development
PLN	Perusahaan Listrik Negara
PPP	public–private partnership
PUCSL	Public Utilities Commission of Sri Lanka
PV	photovoltaic
RERED	Rural Energy for Rural Economic Development
Rp	Indonesian rupiah
SPD	small power distributor
SPP	small power producer
SPPA	standardized power purchase agreement
UNDP	United Nations Development Programme
UNOPS	United Nations Office of Project Services
VHP	village hydro project

All currency in U.S. dollars ($) unless otherwise indicated.

EXECUTIVE SUMMARY

One of the key concerns raised by the developers of mini grids is "what will become of my mini grid when the main grid arrives?" This study attempts to answer this question, using recent experiences of Cambodia, Sri Lanka, and Indonesia, three pioneers in mini grid deployment in rural areas. It reveals that the concerns of mini grid developers are legitimate: Most mini grids were abandoned when the main grid arrived. There are, however, win-win approaches in each of these countries for smoothly integrating mini grid assets with the main grid. Moreover, these strategies have characteristics that bode well for scaling up, enabled by new technologies and innovative policies and regulatory frameworks.

Regulators and policy makers in a growing number of countries—including Cambodia, India, Indonesia, Nepal, Nigeria, Rwanda, Sierra Leone, Sri Lanka, and Tanzania—have issued or proposed rules or regulations that address investors' concerns about what will happen to their investments when the main grid arrives. These rules and regulations typically specify business options for previously isolated mini grids. The five most common options include the following:

- **Small power producer (SPP).** The mini grid converts to a main grid–connected SPP and no longer sells at retail to villagers.
- **Small power distributor (SPD).** The mini grid converts to an SPD that buys its full supply at wholesale from the main grid and sells its purchased electricity to villagers at retail (with or without backup generation).
- **SPP + SPD.** The mini grid continues to sell electricity to its retail customers with its own generated electricity or wholesale purchases from the main grid operator and also sells electricity to the main grid operator when a surplus is available.
- **Side-by-side but not interconnected.** The mini grid continues to serve customers even when the grid arrives, with no electrical interconnection between it and the main grid, even though both operate in the same village.
- **Compensation and exit.** The mini grid goes out of business, and the developer receives some compensation for assets taken over by the main grid operator (typically a government-owned national utility).

The first four options are coexistence options. The fifth option is a going out of business option with compensation.

A sixth outcome—abandonment—is not a recommended practice. It has been the dominant outcome for the community-owned hydro-powered mini grids in Sri Lanka and Indonesia but not for the privately owned diesel-powered mini grids in Cambodia. The report presents recommendations for new regulatory frameworks and technologies that could lower barriers to grid integration.

CASE STUDIES

The three case studies follow a similar structure. Each describes the regulatory, commercial, and technical characteristics before and after the main grid arrived in villages that had previously been served by isolated mini grids.

Cambodia

What happened? Cambodia's isolated mini grids were typically diesel-fired systems built and operated by local private entrepreneurs. They filled an electricity supply vacuum that existed because the main grid did not reach many rural villages during and following the country's turmoil in the 1970s through the early 1990s. The hundreds of isolated mini grids were a spontaneous bottom-up initiative of village-level entrepreneurs, without the support of a government program.

In the early 2000s, a major transformation occurred. The transmission and medium-voltage networks of the national utility, Electricité du Cambodge (EdC), began to expand more rapidly into rural areas. In 2001 the country established the Electricity Authority of Cambodia (EAC), which began a program that required isolated mini grids to obtain licenses and allowed for high retail tariffs in return for investments in equipment that improved service quality and expanded service territory. The EAC also created a process by which isolated mini grids could became SPDs that purchased electricity at wholesale from EdC or neighboring countries at lower prices than the cost of diesel generation. Going beyond a typical regulatory role, the EAC provided ground-level engineering assistance to many licensees in the form of advice on how to build and operate the mini grid's distribution system so that it could integrate with the main grid at some time in the future.

Currently, more than 250 formerly isolated private mini grids in Cambodia have connected to the national grid as SPDs, serving more than 1 million customers.

Before 2016, each SPD charged its own individually calculated cost-reflective tariff. In early 2016, the government announced that the retail tariffs charged by privately owned SPDs would be uniform throughout the country. At the same time, it committed to providing SPDs with an ongoing operational subsidy. The subsidy, which the EAC calculated annually for each SPD, was designed to close the gap between the mandated standardized retail tariffs and each SPD's actual higher costs. It is paid from a Rural Electrification Fund capitalized by EdC.

Why? Cambodia's experience with mini grids is unique: No other country appears to have converted so many previously isolated private mini grids into connected SPDs. Its success reflects several factors:

- The regulator used the "stick" of its licensing authority to induce private mini grid operators to invest money to improve their distribution systems so that they could operate as SPDs once connected to the EdC grid, balanced with a "carrot" of allowing higher tariffs and providing zero-interest loans and subsidies for mini grid investments.

- When the mini grids were connected as SPDs, the national government provided an additional "carrot" of operational subsidies, which were required to support a uniform retail tariff that did not recover SPDs' actual costs.
- EdC viewed the mini grids and later the SPDs as good for its own commercial viability.
- The current distribution margin (that is, the difference between the average retail tariff and the average bulk supply tariff) is wide enough for a well-run mini grid to be commercially viable as a connected SPD.
- Over time the SPDs have grown, allowing them to spread their fixed costs over more customers and over more kilowatt hour (kWh) sales.
- Mini grid owners were motivated to operate efficiently and expand into neighboring villages, sometimes consolidating with other mini grid operators, in order to achieve economies of scale.

Sri Lanka

What happened? Between 1997 and 2012, more than 250 isolated community-owned micro-hydropower projects came into existence in Sri Lanka, with financial support from the government and the World Bank. The program was designed to create village-level mini grids that would be owned and operated by community organizations known as Electricity Consumer Societies (ECSs). The ECSs received assistance from private consultants, who were given project preparation grant payments for each mini grid they helped create that was still operating after six months. Motivated by the payments, the consultants helped identify viable hydropower sites and then convinced households in villages to develop the project. Once the projects were built, the consultants continued working with the ECS to ensure that the projects were operating as intended (at least through the initial six-month period).

These projects were small, with a median size of 27 customers and an average installed capacity of 7.5 kilowatts (kW) (World Bank 2012). At their peak, the ECSs served about 10,000 rural households, with a combined installed capacity of about 4 megawatts (MW).

With the arrival of the main grid of the national utility (the Ceylon Electricity Board [CEB]), more than 100 of the isolated mini grids went out of existence, while three ECSs converted their mini grids into main grid–connected SPPs. As SPPs they sell wholesale electricity to the national utility but no longer provide retail service to village households, as all households were required to disconnect from the mini grid system before they could become retail customers of the CEB.

The conversion to an SPP required investments in interconnection equipment and payments for government approvals. In addition, the ECSs, which were consumer welfare societies, had to be reconstituted as limited liability companies in order to be able to sign the standardized power purchase agreement with the CEB.

The Energy Forum, a Sri Lankan nongovernmental organization (NGO), played a lead role in facilitating the conversion of the three ECSs. It and another NGO, the Federation of Electricity Consumer Societies, hold more than half of the ownership shares in the new limited liability companies. The Energy Forum estimates that more than 50 other abandoned mini grids owned by ECSs could convert to SPPs if financing could be obtained. But conversion would also require agreement between the Energy Forum, the Federation of Electricity Consumer Societies, and individual ECSs as to how the post-conversion equity would be divided among the three entities.

Why? Most ECSs went out of existence when the CEB grid reached the villages they served for several reasons:

- The CEB offered lower (highly subsidized) tariffs and a higher tier of service (generally without a limitation on the size of appliances that can be connected).
- With a median size of 27 customers, the ECSs were too small to survive as commercially viable SPDs.
- To save money, ECS distribution facilities were not built to meet CEB standards.
- The ECSs did not have access to ready sources of financing that would have allowed them to finance the cost of interconnection equipment and expansion of their generation capacity.
- The regulatory requirements to obtain SPP status were designed for larger generators and were too costly for the smaller generators operated by ECSs.
- ECSs were widely viewed as a transitional arrangement designed to provide a basic level of grid electricity until the CEB arrived with better service at a lower price.

Indonesia

What happened? Micro-hydropower projects in Indonesia have benefitted from decades of local capacity building by the government and international donors. Since the 1990s, more than 1,300 projects have been built, of which 1,033 received funding support from the government.

In mini grid-powered villages where the main grid arrived, the transition from isolated to grid-connected mini grids has been a challenge—but not an impossible one. Nine formerly isolated mini grids connected to the main grid, selling electricity at wholesale to the national utility (Perusahaan Listrik Negara [PLN]) under government-specified feed-in tariffs. The additional income generated from wholesale SPP sales to PLN has helped improve the commercial sustainability of the mini grid operations and finance social improvement projects within the village.

In another 150 villages, communities abandoned their mini grids, and most households became PLN retail customers. In 40–50 villages, community-owned mini grids continue to sell electricity on the mini grids' distribution systems, which remain physically separate from the PLN system (the side-by-side but not interconnected option). These mini grids appear to have survived because their tariffs are lower than the tariffs charged by PLN or because many rural households were unwilling or unable to pay the high fees required to connect to the main grid.

Why? Most village projects were abandoned when the national grid arrived. But an important precedent was set in two important connection modalities: (a) five projects connecting as SPPs and selling electricity to the national grid (the SPP option) and (b) four projects continuing to sell electricity to retail customers and interconnecting as SPPs to sell excess electricity to the national grid (the SPP + SPD option). These nine mini grids have pioneered the regulatory environment and technical procedures; others may be able to follow in their footsteps.

Just 6 percent of the mini grids in Indonesia remained in business after the main grid arrived. Two main reasons explain the low rate of interconnections:

- Until very recently, Indonesian law did not allow government-funded micro-hydropower projects to connect. The pool of legally connectable projects was very small because the vast majority of projects received government funding. In May 2017, the government changed the regulation, issuing a decree that explicitly allows the grid connection of government-funded micro-hydropower projects.
- Tariffs for grid-connected micro-hydropower projects have been low ($0.03– $0.04 per kWh). A decree issued in 2017 specifies a 20-year power purchase agreement at tariffs of about $0.037 per kWh for micro-hydropower.

Concluding Observations on the Case Studies

The prevailing mindset is that mini grids and main grid extensions are two separate and mutually exclusive paths to scaling up rural access. In this view of the world, only one of the two approaches can be workable in a village at any given time.

The three case studies provide evidence that the competing alternatives view of the world is an overly simplistic and unproductive way to think about scaling up access. Mini grids and the main grid can complement each other. Once the physical interconnection takes place, different buy and sell transactions between the two delivery technologies can lead to more reliable and less expensive electricity for consumers.

Most mini grids in developed countries (usually described as microgrids) are connected from day 1. In contrast, most mini grids in developing countries are not initially main grid connected and often completely disappear when the main grid arrives. The future could see considerably more integration of isolated mini grids in developing countries with the main grid when it arrives, especially if some key hurdles are overcome. Key barriers to interconnection as an SPP encountered in these case studies include the following:

- **Lack of utility enthusiasm.** Utilities are generally not enthusiastic about interconnecting small distributed generation because the transaction costs are high. These costs include the regulatory tasks involved in designing standardized power purchase agreements, the procedural tasks involved in paying small invoices, the need to conduct studies to review the engineering implications of the interconnection, and sometimes the need to make adjustments to operational practices to ensure that their network remains safe and stable when receiving electricity from small isolated generators. Therefore, it is not surprising that most utilities that have connected to SPPs have been forced to do so by governments or regulatory authorities that see the overall benefit to the country.
- **Low tariffs.** For the reasons described above, the tariffs utilities are willing to pay for generated wholesale electricity from these projects are often low.
- **Interconnection cost.** Interconnection of generation to the main grid involves injecting electricity back into the main grid, which is more difficult than interconnecting a distribution network that draws electricity only from the grid. Connecting as a SPP requires synchronizing generation to the national grid and calibrating a variety of safety relays. In Indonesia, the cost of equipment necessary for grid synchronization—just one component of the interconnection cost—is about $6,000.
- **Legal hurdles.** Interconnection of generation to the national grid has encountered legal hurdles in both Sri Lanka and Indonesia. It takes time to resolve these hurdles, especially if they are embedded in national laws.

Other hurdles exist for community-owned mini grids that wish to become SPDs. Three factors have prevented isolated micro-hydropower mini grids in Sri Lanka and Indonesia from becoming SPDs:

- **Distribution network standards.** The mini grids' distribution networks were often not built to the standards that utilities require for distribution networks.
- **National uniform tariffs.** Once they are connected to the national utility's main grid, village customers expect to pay the same subsidized retail tariffs charged by the national utility. Unless a mini grid's bulk supply purchase price or its operating costs are subsidized, it is unlikely that the difference between the average bulk supply price and the average retail price would be large enough to cover its distribution margin.
- **Legal hurdles.** The entities lacked the legal permission to purchase and resell electricity from the national grid.

In addition to these business model-specific issues, community-scale micro-hydropower mini grids encountered two other barriers:

- **Scale issues.** Projects in Sri Lanka had a median capacity of 7.5 kW. The revenues from projects this small are generally inadequate to cover the full costs of operation.
- **Inability to obtain loans.** Commercial banks are not used to providing loans for village SPPs and have difficulty evaluating the risks associated with these types of projects. Villagers generally lack collateral, and banks are generally not willing to accept the equipment as collateral because it is site specific, heavy, and often encased in concrete. The difficulty in obtaining loans is compounded by the fact that community-managed mini grids usually charge tariffs that are too low, leaving little or no cash reserves to make repairs or serve as equity contributions to finance the physical investments needed to construct a grid interconnection of any form.

Cambodia's diesel mini grids have had remarkable success in transitioning to SPDs. Indeed, more than 250 previously isolated, privately owned mini grids have made this transition. This transition has been technically, financially, and institutionally easier than the transition to SPPs for several reasons:

- EdC is less averse to selling electricity than to buying it from small producers. Selling electricity to an SPD fits its business model; SPDs are yet another customer that takes electricity and sends them money. Working through SPDs means that the utility does not have to deal with directly supplying hundreds of thousands of small customers in relatively small, rural, remote locations.
- Technical interconnection as an SPD is very easy—all that is needed is a meter and (sometimes) a transformer. The relays required for synchronization and safe operating of parallel generation are not required.
- There is little change in the mini grids' business model. Diesel mini grid operators in Cambodia earned revenues by selling electricity to retail end-use customers. After transitioning to SPDs, the operators still earned revenues by selling electricity to retail end-use customers.
- Electricity purchased in bulk from the utility is considerably cheaper than the cost of diesel-generated electricity. The high tariffs that retail customers were used to paying provided generous headroom for small SPDs to charge sufficient margins to remain viable.

Cambodia was able to pioneer mini grids in part because of the country's circumstances—circumstances that many developing countries that remain substantially unelectrified share. As such, its experience provides valuable lessons for the many countries in which hundreds or thousands of new mini grids might be deployed in the coming decade:

- **The costs of low-skilled labor were low.** Licensing and tariff regulation of hundreds of separate SPDs was therefore less financially burdensome than it might be in countries with higher labor costs.
- **Operators were entrepreneurial.** The private owners of the mini grids sought out new customers, pursued opportunities to expand average consumption levels, and actively sought opportunities to buy out neighboring mini grids to achieve economies of scale.

- **The regulator was fully onboard.** The EAC worked very hard to ensure that isolated mini grids made investments, usually financed by family and friends, to bring their distribution networks up to the standards of the national utility.
- **The government provided operating subsidies.** The government of Cambodia ordered small distribution systems to charge uniform, non–cost-recovering retail tariffs and provided operational subsidies to meet the revenue shortfall.

NEW OWNERSHIP AND REGULATORY APPROACHES: PUBLIC–PRIVATE PARTNERSHIPS AND "REGULATION BY CONTRACT"

When communities in Sri Lanka and Indonesia and local private developers in Cambodia made their investments in isolated mini grids, no specific rules or policies were in place to inform them about their options when the main grid reached their villages. Policies addressing the arrival of the grid were not front and center in the discussion surrounding these projects. Instead, the focus was on providing electricity for immediate use.

The arrival of the main grid meant lower prices and fewer restrictions on the appliances villagers could use. For local private developers in Cambodia, the regulator's early decision to issue pure distribution licenses to replace the initial combined generation and distribution licenses ensured a relatively smooth transition to SPDs for the previously isolated mini grids.

This approach of creating policies and regulations as the need arises is not likely to work for governments in Sub-Saharan Africa and Asia that are serious about encouraging private investors to build hundreds and thousands of new mini grids. Private investors, especially large national and international companies, will not be willing to make major investments in mini grids if there is no policy and regulatory clarity as to what their post-interconnection business options will be. The cost of continuing regulatory and policy uncertainty will be the loss of major private investments that could otherwise lead to a significant scale-up of grid-quality electricity in rural communities.

Fortunately, recent developments suggest other approaches. In Haiti, India, Kenya, Madagascar, Nigeria, Sierra Leone, and Zambia, there is growing interest in—and in some instances specific proposals to create—various types of public–private partnerships (PPP) to facilitate private investments in mini grids on a larger scale (see appendix D). One advantage of these proposed arrangements is that the regulatory and policy decisions governing post-interconnection business options can be spelled out in the detailed provisions of the PPP contract.

This "regulation by contract" approach is an alternative to traditional national regulation (see country-specific examples in appendix E). Traditional national regulation relies on case-by-case application of general principles or standards in mini grid rules or laws. A regulatory contract can supplement or substitute national regulations. Regulatory contracts usually provide more project-specific detail than is possible in a national mini grid regulatory framework.

In the late 1990s and early 2000s, regulation by contract was successfully used in a number of privatizations of distribution enterprises (see Bakovic, Tenenbaum, and Woolf 2003), where the regulatory contracts were also supported by World Bank–issued guarantee mechanisms. A similar approach applied to PPPs to promote investments in new mini grids might be feasible. However, the transaction costs to back up regulatory contracts with guarantee mechanisms are not trivial. Therefore, it seems likely that regulatory contracts for mini grids must be implemented without guarantee mechanisms (the current norm) or limited to groups of mini grid projects of a single developer.

RECOMMENDATIONS

Several recommendations emerge from the successes and failures documented in the case study countries. The recommendations are particularly relevant for countries in Sub-Saharan Africa and developing Asia where mini grids might play a significant role in accelerating the pace toward universal access. They include the following:

- **Provide a range of rural electrification options.** Create a regulatory and policy framework that provides incentives to develop a range of rural electrification options, spanning from solar home systems to mini grids to the national grid.
- **Provide a range of post-interconnection business options.** Develop rules that offer a range of post-interconnection business options for what happens "when the big grid reaches the little grid." The key options are operating as an SPP, an SPD, or a combination of the two.
- **Determine what compensation will be offered for "buy-out."** Create rules that specify how mini grid developers will be compensated for their assets in the event of a "buy-out" when the main grid arrives. Specify when the mini grid operator's work in "pre-electrifying" a village merits compensation.
- **Streamline regulatory requirements.** Streamline regulatory processes and requirements so that licensing, permission to interconnect to the main grid operator, retail tariff setting, and other business and environmental approvals are integrated, and duplication of government review processes are minimized.
- **Specific interconnection technical standards.** Specify technical standards that allow mini grids to be interconnected to the main grid without significant additional investments when the main grid arrives.
- **Establish complementary roles.** Encourage utilities to accept complementary business roles for mini grids when the two grids connect.
- **Facilitate joint ventures.** Develop rules that enable communities to enter into joint ventures with private developers for new or expanded mini grids, to enhance the likelihood that SPPs will be a viable post-connection option.

- **Create parity for capital cost subsidies.** If capital and operating subsidies are provided to the main grid owner for grid extension and for operating their own mini grids in rural areas, provide comparable subsidies to private mini grid operators for capital costs so that the playing field is level. In general, operating cost subsidies should not be provided to mini grid operators because it would create a heavy and probably unsustainable financial burden on governments. Moreover, operating subsidies should not be needed if mini grid operators have explicit authority to charge tariffs above the uniform national tariff.

In light of the limited scope of this study, and the likely emergence of new third-generation mini grids, further research with a strong operational focus should be undertaken. These studies should focus on the following:

- **Main grid-connected mini grids.** Examine how mini grids can be connected (in islanded and non-islanded modes) to the main grid from day 1 of operations.
- **Interconnecting solar hybrid mini grids.** Analyze the commercial, technical, and regulatory issues in interconnecting solar hybrid mini grids to the main grid.
- **Magnitude of existing subsidies.** Provide estimates of existing capital and operational subsidies in countries that are promoting mini grids and main grid extension. These would include:
    - general subsidies to publicly owned national and regional entities that provide distribution service
    - specific subsidies for the connection of new rural customers through main grid extension by publicly owned national and regional distribution
    - specific subsidies to publicly owned national and regional entities that own and operate isolated mini grids.
- **Regulatory contracts for mini grids.** Describe, compare, and evaluate the regulatory contracts developed in Bangladesh, Haiti, Mali, Myanmar, Nigeria, and other countries (see appendix E).
- **Competitive procurement for mini grids.** Describe, compare, and evaluate the competitive procurements for mini grids in Haiti, Nigeria, Sierra Leone, Uganda, and Zambia.
- **Benchmarking of hard and soft costs.** Develop a cross-country database on the "hard" and "soft" costs of interconnection, as they vary by technology, distance to the main grid, interconnection voltage levels, and the functions performed by the mini grid.
- **Standardized spreadsheets.** Create a spreadsheet template that can be used to calculate the costs and revenues of interconnecting previously isolated mini grids.
- **Technical primer for non-engineers.** Develop a primer for non-engineers on the engineering aspects of interconnection and different levels of islanding.

1

INTRODUCTION

Most mini grids[1] in developing countries begin life as isolated electrical systems that are not connected to the country's main grid.[2] They arise because expansion of the main grid has been slow and unpredictable. In the words of one villager in Tanzania served by a mini grid, "We got tired of waiting."

In recent years, the main grid has expanded to reach more rural areas in many African, Asian, and Latin American countries.[3] What happens to existing mini grids when the main grid arrives? This study answers this question by studying the experiences of three Asian countries: Cambodia, Indonesia, and Sri Lanka.

COUNTRY OVERVIEWS

Cambodia

In Cambodia, local entrepreneurs built and operated isolated mini grids, typically fired by diesel. They filled a vacuum that existed because the main grid did not reach many rural villages during and following the country's turmoil in the 1970s through the early 1990s.

In the early 2000s, as the main grid expanded more rapidly into rural areas, more than 250 previously isolated mini grids became small power distributors (SPDs). SPDs purchase electricity at wholesale, either from the national utility (Electricité du Cambodge [EdC]) or neighboring countries.

To increase the deployment of electricity, improve quality, and reduce high retail tariffs from diesel mini grid levels ($0.4–$1.0 per kWh), the Electricity Authority of Cambodia (EAC) put in place a comprehensive program that grants long-term distribution licenses to private sector franchisees that invest in utility-quality distribution networks and extend their networks throughout prescribed service territories. In 2016 retail tariffs to end-users on these rural distribution systems were standardized and subsidized, with the gap between retail tariffs and project-specific cost-recovery tariffs paid out of a Rural Electrification Fund capitalized by EdC. The program has been successful. In 2005 isolated mini grids served fewer than 100,000 customers. With the widespread conversion to SPDs, the SPDs and remaining isolated mini grids served more than 1 million customers in 2015.

Sri Lanka

Between 1997 and 2012, more than 250 isolated hydro-powered mini grid projects owned by community organizations known as Electricity Consumer Societies (ECSs) came into existence in Sri Lanka, with financial support from the government and the World Bank. The ECSs received considerable assistance from private consultants, who were paid for each mini grid they helped create that was still operating after six months.

When the national utility's main grid reached these villages, more than 100 of the isolated mini grids were abandoned. The national utility, the Ceylon Electricity Board (CEB), became the new electricity supplier to most ECS members.

Only three community-owned mini grids succeeded in converting to grid-connected small power producers (SPPs). In all three instances, two nongovernmental organizations (NGOs) provided heavy technical support. Since the conversion, the three mini grids no longer provide retail service to their members. Their sole source of revenue comes from bulk sales of electricity to the CEB.

Indonesia

Micro-hydropower projects in Indonesia have benefitted from decades of local capacity building by the government and international donors. Since the 1990s, more than 1,300 projects have been built, of which 1,033 received funding support from the government.

Nine formerly isolated micro-hydropower mini grids have connected to the national utility (Perusahaan Listrik Negara [PLN]) grid, selling electricity at wholesale to PLN under government specified feed-in tariffs. The income generated from these sales has helped increase the commercial sustainability of the mini grid operations and improved social conditions in the village.

In another 150 cases, communities abandoned their mini grids after the main grid arrived, and most community members became PLN retail customers. In 40–50 villages, the community-owned mini grids continue to sell electricity on the mini grids' existing distribution systems, which remain physically separate from the PLN distribution system. These mini grids appear to have survived because they charged retail tariffs that are lower than the tariffs charged by PLN on these islands, or because rural households were unwilling or unable to pay the high fees required by PLN to connect to the PLN grid.

OPTIONS FOR PREVIOUSLY ISOLATED MINI GRIDS

Regulators and policy makers in a growing number of countries—including Cambodia, India, Indonesia, Nepal, Nigeria, Rwanda, Sri Lanka, and Tanzania—have issued or proposed rules or regulations that specify business options for previously isolated mini grids. The five most common options include the following:

- **Compensation and exit.** The mini grid goes out of business, and the developer receives some compensation for assets taken over by the main grid operator (typically a government-owned national utility).
- **Small power purchaser (SPP).** The mini grid converts to a main grid-connected SPP and no longer sells at retail to villagers.
- **Retail + SPP.** The mini grid continues to sell electricity to its retail customers with its own generated electricity or wholesale purchases from the main grid operator, and also sells electricity to the main grid operator when a surplus is available.

- **Small power distributor (SPD).** The mini grid converts to an SPD that buys its full supply at wholesale from the main grid and sells its purchased electricity to villagers at retail (with or without backup generation).
- **Side-by-side but not interconnected.** The mini grid continues to serve customers as it previously did, even when the main grid arrives, with no electrical interconnection between it and the main grid, even though both are operating in the same village.

The first option is the going out of business option. The other four are coexistence options.

A sixth outcome—abandonment—has been the dominant outcome for the community-owned hydro-powered mini grids in Sri Lanka and Indonesia. The case studies explain why abandonment of mini grids has been so prevalent in these countries.

SCOPE OF THIS STUDY

The three country case studies follow a similar structure. Each describes the regulatory, commercial, and technical characteristics before and after the main grid arrived in villages that had previously been served by the isolated mini grids. The studies describe real-world experiences for the SPP option, the SPD option, and the retail + SPP option for two generating technologies (mini-hydropower and diesel). They do not provide examples of the compensation and exit post-interconnection business outcome or other generating technologies (solar, biomass, hybrids). Such an effort would require additional case studies. It will be especially important to examine the post-connection options for solar hybrid mini grids, which are emerging as the dominant technology choice throughout Sub-Saharan Africa and in at least two countries in Asia (Bangladesh and India).

ENDNOTES

[1]There is no universally accepted definition of a mini grid. This report defines it as a low-voltage distribution grid that receives electricity from one or more small generators (usually renewable) and supplies electricity to a target group of consumers, typically including households, businesses, and public institutions. A mini grid may be electrically connected or electrically isolated from the main grid. A mini grid that is connected to the main grid may have the ability to island (separate) its operations from the electrical system of the main grid.

[2]In developed countries with 100 percent electrification, microgrids (the more common term in developed countries) are typically connected to the main or macro grid from the outset. The principal motivation for microgrids has been to enhance reliability in the case of extreme weather events. Regulators and policy makers in at least three U.S. states (California, Minnesota, and New York) are considering proposals to expand the roles of microgrids by allowing them to buy and sell electricity in regional bulk power markets (see, for example, New York State's "Reforming the Energy Vision" [https://rev.ny.gov]). In New Jersey, the state government has awarded grants to 13 townships to study the feasibility of creating microgrids that would, at a minimum, provide electricity to critical facilities (police, fire, hospitals) if the main grid is unable to supply electricity because of extreme weather or other events. See appendix A for a comparison of microgrids in high income countries with mini grids in low income countries.

[3]The focus of this paper is on mini grids in rural areas. Household connection rates are generally lowest in rural areas. But there are also many households in urban and peri-urban areas that do not have grid quality electricity. For example, it has been estimated that about 110 of the 600 million people in Africa live near the main grid. A recent paper argues that these 110 million people living near the grid could also be connected at lower cost by privately operated mini grids than by connecting them to the nearby main grid. See Benjamin Attia and Rebekah Shirley, *Living Under the Grid: 110 Million of Africa's Unconnected Customers Represent a Massive Opportunity,* GTM Research Spotlight, December 8, 2017. Available at https://www.greentechmedia.com/articles/read/living-under-the-grid-110-million-of-africas-unconnected-customers-represen#gs.a0A7InE.

2

CAMBODIA: FROM ISOLATED DIESEL MINI GRIDS TO DISTRIBUTION FRANCHISEES

More than 250 formerly isolated private sector mini grids have connected to the national grid as small power distributors (SPDs), known in Cambodia as distribution licensees. They purchase electricity at wholesale from the national utility, Electricité du Cambodge (EdC), and resell it at retail to households and businesses.

Before the arrival of the national grid, these rural mini grids used diesel generators. Tariffs varied depending on the size of the mini grid and (especially) the price of diesel fuel. They ranged from CR 1,600 ($0.40) to CR 4,100 ($1) per kWh.[4]

Retail tariffs for these new distribution franchisees are now standardized across the country at CR 480 ($0.12) or CR 800 ($0.20) per kWh, depending on the customer type. A government-mandated subsidy scheme helps cover the gap between these standardized tariffs and the SPD's full costs (power purchase plus distribution costs).

The conversion from isolated diesel-fired mini grids to main grid-connected SPDs has led to increases in the number of customers served and improvements in the quality of supply. The number of customers served by these small private electricity systems rose from fewer than 100,000 in 2005 to more than 1 million in 2015. Between 2003 and 2015, the number of licensees providing less than 24 hours of service decreased from 50 out of 85 (59 percent) to 5 out of 311 (less than 2 percent) (Castalia Strategic Advisors forthcoming).

POWERING HOUSEHOLDS BEFORE A VILLAGE IS CONNECTED TO THE MAIN GRID

Electrical infrastructure in Cambodia was damaged and neglected during the violence and chaos of the 1970s and 1980s. Reconstruction restarted in the 1990s.

Electricity in Phnom Penh and large towns was historically under government ownership and control—generally by EdC, and sometimes by provincial governments. EdC also supplied electricity to customers in about a dozen areas near Vietnam, with bulk electricity it purchased from Vietnam. In border areas near Vietnam, Thailand, and the Lao People's Democratic Republic, private entrepreneurs purchased electricity at bulk from neighboring countries for resale to retail customers on small privately owned and operated distribution systems.

Outside major towns and border areas, rural electricity supply was rare. Where it existed in the 1990s, it was in private hands. Local entrepreneurs set up diesel generators that produced 24–1,520 kW; most mini grids generated less than 200 kW. They began by supplying electricity to a few neighboring households, expanding little by little as finances permitted.

There is no firm figure on the number of these rural electricity enterprises. A World Bank-commissioned study conducted in 2001 by Enterprise Development Cambodia developed a list of 218 enterprises, including those registered with the government and informal mini grids encountered while conducting field visits in 15 of Cambodia's 24 provinces. Most of them supplied electricity for a few hours each evening; some provided power in the morning and the evening. These diesel mini grids typically provided electricity at a Tier 2 and 3 level on the World Bank's Multi-Tier Framework.[5] Typical payments in 2001 ranged from $4.40 to $12 a month (Meritec Limited 2001).

Some systems had transformers and medium voltage (22 kilovolts [kV]) lines, but most were low voltage (230–380 volts) only, limiting both the maximum electrical load and the distance across which distribution lines could be extended.[6] Electricity supply in these private mini grids was generally not very stable. Most generators were purchased secondhand, and distribution wiring networks were often undersized and not built to standards of any kind. Distribution systems were generally in bad shape, with inadequate poles, undersized conductors, and poor splices.

Retail tariffs of $0.40–$1.00 per kWh were much higher than the (highly subsidized) tariffs in urban areas served by EdC, which ranged from $0.15 to $0.25 per kWh, depending on the location. From the beginning, Cambodia was thus accustomed to high tariffs and variation in tariffs both across villages and between villages, on the one hand, and towns and cities on the other.

REGULATORY FRAMEWORK FOR ISOLATED MINI GRIDS

Throughout the 1990s, some mini grids operated under licenses from the provincial government or the ministry. Licenses were issued sporadically, however, and some projects operated without licenses.

An electricity regulator, the Energy Authority of Cambodia (EAC), was established under Cambodia's Electricity Law, promulgated in February 2001. From its beginnings, it adopted the goals of expanding service to more areas, improving quality, and regulating tariffs. The law required that all providers of electric power service obtain a license. Service providers were given a six-month window to apply for licenses.

Starting in February 2002, the EAC began issuing "consolidated generation and distribution licenses" to EdC and private isolated mini grids, that both generated electricity and sold it to retail customers over private distribution networks. In April 2002, it issued its first distribution licenses to a distribution franchisee that purchased electricity at wholesale tariffs from EdC (all licenses are publicly available for download at the EAC website http://eac.gov.kh/license/index?lang=en).

In considering the regulatory approach to use with mini grids, the EAC decided to plan for smooth integration of the mini grid with the main grid when the main grid arrived. One key aspect of this effort has been the tying of the licensing approval process to improvement in mini grid distribution infrastructure, so that it is main grid ready. Early on, the EAC issued two-year licenses to isolated mini grids, with the condition that the license would be extended as long as the infrastructure was improved and reports regularly filed. For mini grids that completed improvements to their distribution networks, the EAC issued licenses for 5–20 years.

The license granted describes a geographical service area (see map 2.1 for an example). The licensee is obligated to expand its operation to the entire licensed area throughout the duration of the license. If it fails to do so, it can lose its license, which can be given to another private company. (To date, the EAC has not withdrawn any licenses, as compliance with network expansion requirements has been good.) In addition to the threat of license revocation, the EAC provided licensees with licenses of five years or longer with financial assistance, in the form of loan guarantees, interest-free loans, and grants through the Rural Electrification Fund's Program for Providing Assistance to Develop Electricity Infrastructure in Rural Areas.

EAC staff made frequent site visits to determine whether required improvements had been made. The transactions costs involved in this monitoring proved to be high because of the poor state of roads and low population density (89 persons per square kilometer, compared with 135 in Thailand and 299 in Vietnam). To address this issue, in 2013 the EAC and the Provincial Department of Mines and Energy (PDME) reached an agreement to entrust certain monitoring duties and assistance with dispute resolution to local PDME officers in provinces as representatives of the EAC. Licensees submitted quarterly and annual reports to the EAC using forms available on the EAC website.

These rules incentivized improvement in the quality of the distribution system in these isolated mini grids, bringing them up to sufficient technical standards to interconnect with and purchase electricity from EdC when it arrived. In all provinces, licensees have met or exceeded contracted distribution extension requirements. As of 2014, all distribution licenses had terms of five years or more.

The EAC was more than a traditional regulator. In addition to the traditional regulatory tasks of issuing licenses and setting maximum prices and minimum quality of service standards, it provided ground-level engineering assistance to many licensees. This assistance typically took the form of advice on how to build and operate the mini grid's distribution system so that it could integrate with the main grid at some time in the future.

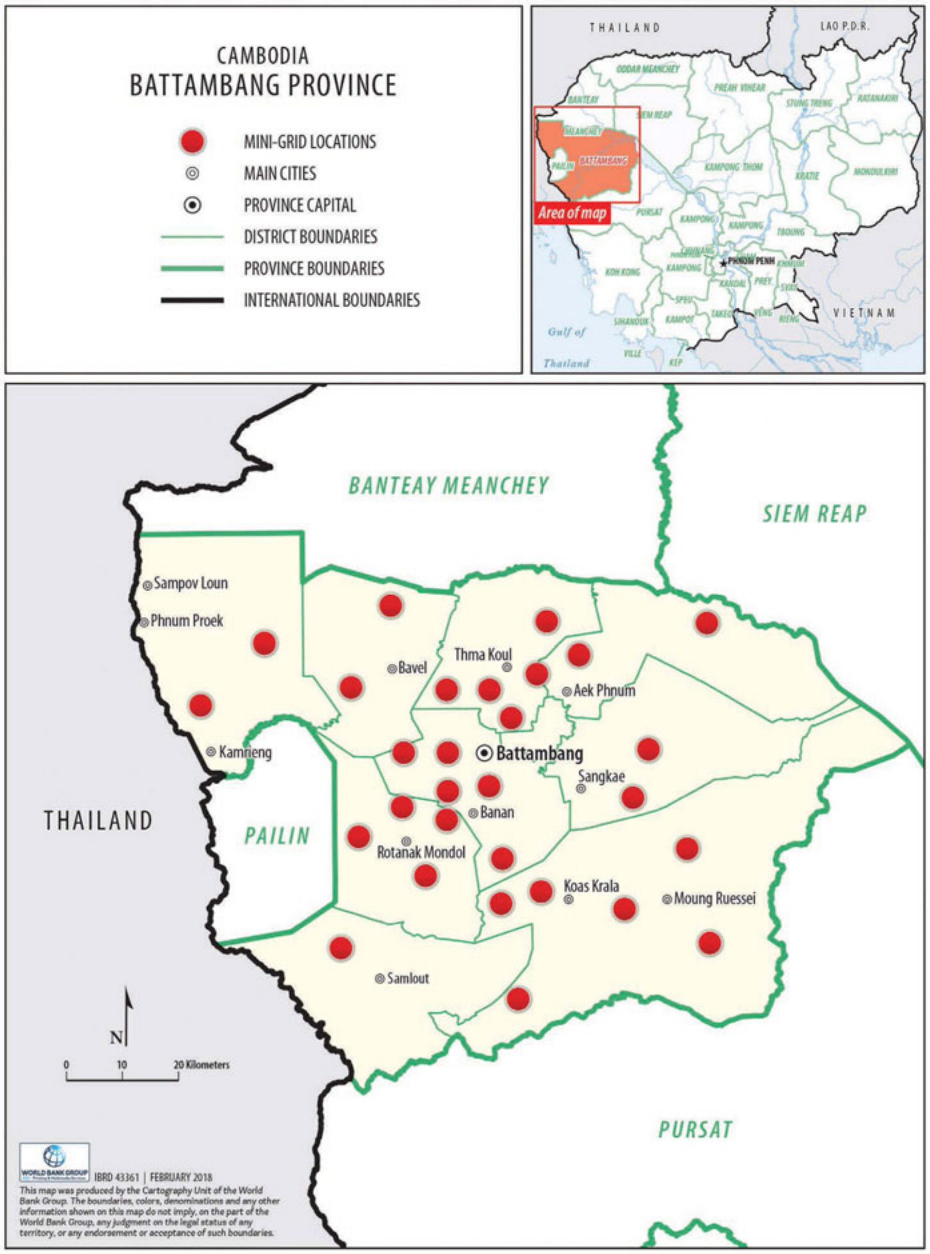
WHAT HAPPENED AFTER THE MAIN GRID ARRIVED?

With the arrival of the main grid (either EdC or electricity from across the border), mini grids generally connected to the main grid and switched business models to become retail distributors of electricity purchased at wholesale. Each formerly isolated mini grid was exposed to a new set of regulatory, commercial, and technical arrangements.

Consumers saw an increase in supply availability and affordability. Diesel mini grids supplied a few hours of expensive electricity every evening; with the arrival of the main grid, electricity was supplied 24 hours a day at a much lower cost. In World Bank Multitier Framework terms, service levels rose from Tier 2 or 3 to the higher Tier 4 or 5.

MAP 2.1

Electricity Licensees in Battambang Province, Cambodia, 2015



Source | *Adapted from the EAC website (http://eac.gov.kh/wp-content/uploads/2016/09/02-_Battambang2015.png), which provides maps of every province and copies of all licenses.*

Regulatory Aspects

Licenses to Distribution Franchisees

Distribution licenses are available for companies that wish to purchase electricity at wholesale rates from EdC for resale to retail customers. A conversion process allows mini grids that were previously isolated and generated their own electricity to retain their generator for backup power until the transition is complete. Grid-connected licensees often maintain their consolidated (generation plus distribution) license for several months and retain their generators for use during power outages on the national grid. After some months, the EAC ensures that the consolidated license is converted to a distribution license. Once the license type is changed to distribution, the generator is generally no longer operated, because the allowable retail tariff is not sufficient to cover generator operation (as discussed below).

The EAC's heavy workload has caused delays in changing licenses from consolidated to distribution. At the time, the authors conducted interviews for this study, dozens of installations were reselling electricity purchased at wholesale from EdC while operating under consolidated licenses.[7]

Most distribution licensees purchase electricity from EdC. Some electricity is also purchased from neighboring countries. In about 50 locations, private distribution licensees in Cambodia purchase electricity from Vietnam. Near the Thai and Lao borders, private entrepreneurs purchase electricity at bulk rates from Thailand and Lao PDR for resale to retail customers. The EAC does not regulate the wholesale tariffs charged by foreign entities selling to SPDs. The wholesale tariffs charged by these foreign suppliers are generally lower than the wholesale tariffs charged by EdC to SPDs in Cambodia.

Regulation of Retail Tariffs Charged by Licensees

The EAC regulates retail tariffs for both distribution franchisees and isolated mini grids. It determines subsidies to distribution franchisees to reduce and standardize the tariffs they charge. The subsidy program received attention from the highest levels of Cambodia's government. In 2015, the prime minister announced plans for the program as part of a broader strategic initiative to reduce tariffs by 2020.[8]

For distribution licensees connected to the national grid, the tariff retail customers pay is a standardized tariff that is the same for distribution franchisees across the country. This tariff is like a national uniform tariff that applies only to distribution licensees. Table 2.1 shows the standard tariffs for different customer classes served by distribution licensees.

Under this tariff standardization program, the difference between the standard tariff and the distribution franchisee's calculated full cost–recovery tariffs (the tariff that would cover their full costs, but which they are not allowed to charge) is made up by cross-subsidies administered by EdC through the Rural Electrification Fund.[9]

The EAC calculates full cost–recovery tariffs based on a standardized spreadsheet for each project.[10] The model used takes into account depreciated asset bases, operations and maintenance, projected electricity sales to different customer classes (and their tariffs), and electricity purchase costs (in the

TABLE 2.1

Standardized Tariffs Charged by Distribution Franchisees That Purchase Wholesale Electricity from the National Grid

CUSTOMER CATEGORY	TARIFF (PER KWH)
Household consuming less than 10 kWh per month	CR 480 ($0.12)
Agricultural customer pumping water between 9 P.M. and 7 A.M.	CR 480 ($0.12)
Household consuming more than 10 kWh per month	CR 800 ($0.20)

case of distribution franchisees). The EAC calculates full cost–recovery tariffs that would generate an internal rate of return of 10 percent in a well-managed company. For distribution licensees, calculated full cost–recovery tariffs are typically in the range of Cambodian riel (CR) 1,050–1,200 ($0.2625–$0.300) per kWh, but some smaller distribution franchisees or franchisees recently connected to the national grid have full cost–recovery tariffs as high as CR 1,700 ($0.425) per kWh.[11] The EAC recalculates the full cost–recovery tariffs for each licensee annually.

To take an example of a typical distribution franchisee with a calculated full cost–recovery tariff of CR 1,100, the total subsidy payments from the Rural Electrification Fund it receives depends on the composition of its customers. It receives a subsidy of CR 620 ($0.155) per kWh for sales to agriculture and customers consuming less than 10 kWh per month and a subsidy of CR 300 ($0.075) per kWh for customers consuming more than 10 kWh per month (table 2.2).

The distribution licensee receives a 27 percent subsidy on its sales to residential customers consuming more than 10 kWh per month and a 56 percent subsidy on sales to its smaller, poorer customers. This operational subsidy is in addition to any capital subsidy received by the operator.

About $30 million was allocated for this operational subsidy in EdC's 2016 general budget—about a third of its annual profit of roughly $100 million. The remainder, about $70 million, is spent on capital

TABLE 2.2

Example of Typical Distribution Franchisee with Calculated Full Cost–Recovery Tariff

ITEM	AMOUNT PER KWH
Subsidy for electricity sold to agriculture and low-consumption customers	
Calculated full cost recovery	CR 1,100 ($0.275)
Minus standardized tariff	CR 480 ($0.120)
Operating subsidy	CR 620 ($0.155)
Subsidy for electricity sold to households consuming more than 10 kWh per month	
Calculated full cost recovery	CR 1,100 ($0.275)
Minus standardized tariff	CR 800 ($0.200)
Operating subsidy	CR 300 ($0.075)

subsidies and low-interest loans and investments in medium- and high-voltage expansion. The operational subsidy benefits about 690,000 rural customers, which works out to $43 per customer a year (about $3.50 a month).[12] Reductions in standard tariffs are expected to be imposed every year until 2020. Increased operational subsidies will be needed in each of the next few years unless the costs of distribution licensees fall or retail tariffs rise.

In the case of remaining isolated mini grids, the Rural Electrification Fund provides no subsidies, and the operator is allowed to charge a full cost–recovery tariff. As with distribution licensees, the tariff is calculated separately for each project. The model used for the calculation considers the full depreciated asset base, operations and maintenance, projected electricity sales, sales volumes to different customer classes (and their tariffs), and fuel costs (based on a diesel price index mechanism). When mini grid operators make fuel purchases, they must do so from approved fuel vendors and send the EAC a copy of their fuel invoices. If fuel prices rise or fall outside a specified price band, the tariff is increased or decreased based on a formula.[13]

There is some evidence that the EAC has tightened the full cost–recovery calculation in recent years. It does not automatically accept the actual distribution line losses of each licensee. Instead, it substitutes stricter (lower) benchmarked values. It has also disallowed some capital costs from the rate base component of the calculation. Both regulatory decisions reduce the full cost–recovery numbers, which in turn lowers the operating subsidy individual licensees receive. In effect, the EAC is saying to licensees: "Your costs of production would be lower if you operated more efficiently. We will use our calculated efficient production costs in setting the amount of operating subsidy you will receive."

The EAC is tightening the allowed distribution margin (the difference between total costs of distribution and sale and power purchase costs) for SPDs. There is always a danger that if the distribution margin becomes too small, SPDs will no longer be commercially viable, raising the question of who will take over for SPDs if they go out of business.

Regulation of Wholesale Tariffs

Wholesale tariffs for electricity sold to distribution franchisees are also regulated. They range from CR 508 to CR 720 ($0.127–$0.180) per kWh, depending on whether the electricity is coming from EdC or a private transmission line, the voltage of the connection, and the transmission line distance.[14] A comprehensive spreadsheet-based model is used to calculate relevant wholesale tariffs based on depreciated costs, expected electricity sales, and other inputs.

Commercial Aspects

Grid-interconnected mini grids in Cambodia have overwhelmingly adopted the distribution franchise model (referred to as SPDs in other countries), purchasing electricity at wholesale from the national utility for resale to retail customers. As of July 2016, an estimated 250 private sector distribution franchisees were in operation. In 2015, the typical distribution franchisee reselling EdC electricity had about 2,800 customers.[15] A review of license holders indicates that small, local family businesses generally owned these projects.

With the expansion of the EdC transmission network into the service territory of isolated mini grids, licensees have been eager to connect to EdC (or in some cases, cross-border utilities) as soon as possible. Connection allows the mini grid operator to take advantage of wholesale electricity prices that are lower than the costs of self-generation using diesel and to shed the burden of operating and maintaining a diesel generator while retaining opportunities for profits.

With electricity tariffs to end users dropping from $0.40–$1.00 per kWh to CR 800 ($0.20) or lower, customers now purchase more electricity. In 2014, the typical customer connected to national grid power (whether as a direct EdC customer or a customer of a distribution franchisee) consumed 3,064 kWh; the typical isolated mini grid customer consumed just 324 kWh according to the EAC's 2015 annual report.

The EAC typically allows a month or more time lag in reducing tariffs to reflect the change to the cheaper grid-connected source of electricity. This period of high revenues/low costs provides a cash-flow boost that is useful in covering the costs incurred for the new equipment required to interconnect to the main grid.

In many countries, utilities want to take over electricity distribution to retail customers once their lines reach a village. Cambodia's utility has not done so. EdC supported the conversion of isolated mini grids to SPDs because it lacked the personnel and funds needed to expand the grid to reach individual distribution networks. Conversion allowed EdC to focus on building out medium-voltage networks to existing mini grid distribution networks, providing more people with electricity than would have been possible if EdC had also built its own (in many cases duplicative) retail distribution network. It made business sense for EdC to support the isolated mini grids that converted to SPDs. By taking this approach, EdC avoided the costs of connecting new customers, introducing them to grid-based electricity, and sought out customers with larger productive loads. It left the heavy lifting of market development to the owners and operators of isolated mini grids.

Distribution franchisees and isolated mini grids have found it difficult to finance investments in improving the quality and coverage of their distribution networks. Mini grids and distribution franchisees in rural areas have limited options, including borrowing from relatives or informal lenders at high interest rates. Access to credit from commercial banks, such as ACLEDA Bank, is limited.

To help expand access to electricity, in 2004 the government of Cambodia issued Royal Decree NS/RKT/1204/048, which established the Rural Electrification Fund. The fund was initially co-capitalized by the World Bank and the Cambodian government. Under this initial program, the World Bank provided $45 per connection for 50,000 new connections in rural areas.[16] In August 2012, operation and funding of the Rural Electrification Fund was transferred to EdC, which expanded programs.

Two of the fund's programs support mini grids. The Program for Power to the Poor (P2P) provides interest-free loans to households for interconnection fees, in-house wiring, and the cost of wires from the connection point to the house. The maximum loan is CR 480,000 ($120), with a maximum tenor of 36 months. The mini grid licensee collects the loan payments as part of a bill payment.

The Program for Providing Assistance to Develop Electricity Infrastructure in Rural Areas provides financing for construction of distribution networks and other electricity supply infrastructure for licensees that have licenses of at least five years. EdC uses population density and economic development indicators to decide how much funding a mini grid is eligible to receive:

- In areas with low density and low economic development, the Rural Electrification Fund provides grants of up to 30 percent of the project infrastructure cost, with up to an additional 60 percent in the form of an interest-free loan.
- In areas with medium population density, where electrification may not be profitable, if the licensee had to pay interest on a loan, the Rural Electrification Fund provides interest-free loans. These loans have a limit of 50–60 percent of the cost of the infrastructure owned by the licensee, cannot exceed $300,000 per project, and have a maximum tenor of eight years. In the event of default, the license reverts to EdC.
- In areas with high population density, where electrification is more economically viable, the program was designed to provide bank guarantees. No loan guarantees appear to have been made, however, because the Ministry of Economics and Finance has been reluctant to approve them.

Funds for the interest-free loans and grants come from the German KfW and EdC.

By 2016, most higher-density areas had been covered. The remaining areas are largely recipients of interest-free loans or both grants and interest-free loans.

Technical Aspects

Electricity does not flow from the distribution franchisee (SPD) back to the main grid; the flow is unidirectional rather than bidirectional. If they are retained, generators are used only as backup when power from the main grid is not available. When operated, the remaining generators are thus isolated from the main grid. For this reason, there is no need to synchronize generators with the grid (in contrast to the small power producers [SPPs] in the Sri Lanka and Indonesia described in this report). Therefore, the arrival of the main grid and subsequent interconnection as distribution franchisee involves relatively uncomplicated technical upgrades. Indeed, most of the upgrades to poles, conductors, and metering needed to be grid ready will have already been installed as a condition of the consolidated distribution/generation license. The actual interconnection with the national grid generally requires only a transformer, a meter, and fused switchgear that disconnect loads in the event of an overcurrent condition.

CONCLUDING OBSERVATIONS

Cambodia's experience with mini grids is unique: No other country appears to have successfully converted so many isolated mini grids into connected SPDs. Several reasons may have contributed to its success:

1 | The regulator used the "stick" of its licensing authority to induce private mini grid operators to invest money to improve their distribution systems so that they could operate as SPDs once connected to the EdC grid.

2 | EdC viewed the mini grids and later the SPDs as good for its own commercial viability.

3 | The national government was willing to provide operational subsidies to the SPDs, which were required if they were to charge a uniform retail tariff that did not recover their costs. At least so far, the distribution margin has been high enough for a well-run mini grid to be commercially viable as a connected SPD. These margins were enabled in part by the fact that customers were accustomed to very high tariffs as a consequence of widespread earlier use of diesel generation.

4 | Mini grid owners were motivated to operate efficiently and expand into neighboring villagers to achieve economies of scale.

ENDNOTES

[4]A 2001 survey of 45 rural electricity enterprises by Enterprise Development Cambodia found that most charged $0.40–$0.70 per kWh. The Electricity Authority of Cambodia (EAC 2016) lists approved diesel mini grid tariffs as high as CR 4,100 ($1) per kWh

[5]The Multi-Tier Framework describes tiers of service based on key service characteristics, including the ability to gain access to energy that is adequate, available when needed, reliable, of good quality, convenient, affordable, legal, healthy, and safe for all required energy services. Tier 2 powers general lighting and television, providing less than 200 watts per customer, with hours of service that are limited to a few hours a day (for details, see Bhatia and others 2013).

[6]The maximum distance a low-voltage distribution line can be extended depends on the load served, the gauge (thickness) and material type of the low-voltage wire, and whether the circuit is three-phase or single. Low-voltages lines are typically no more than 1 kilometer long.

[7]The heavy workload may be a consequence of the EAC's intense regulatory oversight of mini grids, which involves inspections and frequent reviews of reports and detailed tariff calculations.

[8]In addition to standardizing tariffs of distribution franchisees connected to the national grid, the initiative also reduced tariffs for customers of EdC connected to the national grid.

[9]Peru uses a similar cross-subsidy scheme for customers of isolated mini grids (see Tenenbaum and others 2014). One difference is that the subsidy scheme in Peru is administered by the national electricity regulator rather than a national or regional government-owned utility. Tanzania proposed a different approach. In its 2015 mini grid rules, the national electricity regulator (the Energy and Water Utilities Regulatory Authority (EWURA) required that the national utility (the Tanzania Electric Supply Company Limited [TANESCO]) supply bulk power to distribution licensees at a discounted (non–cost-recovering) wholesale tariff. The expectation was that this subsidy to SPDs in their bulk supply purchase price would be paid for by TANESCO's other customers. In EWURA's 2017 mini grid rules, this proposed subsidy was eliminated from the rules; it was not replaced by any other subsidy mechanism.

[10]Two key implementation issues arise in making these calculations. First, the EAC makes 250 separate cost of service calculations, one for each distribution franchisee. The submitted numbers must be audited at least on a spot basis. Second, the EAC makes a decision about the level of line losses on the mini grid's lower-voltage (LV) distribution lines it will use in making the cost of service calculation. The EAC has decided not to automatically accept the LV losses reported by individual mini grids. Instead, it uses a benchmarked value for LV losses. If an individual distribution franchisee can achieve LV losses that are lower than the benchmarked value, it will earn more money. If its LV line losses are higher than the benchmarked value, it will earn less money. LV line losses for distribution franchisees were recently at about 15 percent. The figure represents an improvement from about 20 percent in 2005, but it is still higher than the 4–5 percent losses achieved by EdC on its LV lines.

[11]A detailed list of the monthly regulated retail tariffs charged licensees, including distribution franchisees, in 2014 is provided in annex 7 of the EAC annual report. eac.gov.kh/wp-content/uploads/2015/07/report-2014en.pdf.

[12]For a description of a similar subsidy mechanism in Peru, see Revolo (2009).

[13]The Nigerian electricity regulator recently adopted a standardized spreadsheet with a multiyear tariff-setting system for isolated mini grids. It eliminates the need to come back to the regulator for approval of new tariffs whenever there is a significant change in costs. See annex 15 of the Nigerian Electricity Regulatory Commission's regulations for mini grids (http://www.nercng.org/index.php/library/documents/Regulations/NERC-Mini-Grid-Regulation/).

[14]Table 18 in the EAC's 2014 annual report shows all wholesale tariffs to distribution franchisees.

[15]As of 2014, 241 distribution franchisees were distributing and reselling EdC electricity to 686,308 customers (see annex 5B of the EAC's 2014 annual report).

[16]A subsidy of $45 per connection is low compared with connection subsidies in other countries. Mali and Tanzania subsidize rural household connections at 10 times this rate or more.

3

SRI LANKA: TRANSITIONAL COMMUNITY-OWNED MINI GRIDS

In 1994, when Sri Lanka was in the midst of a civil war, only about 38 percent of the population had access to the grid—and the percentage was even lower in rural areas. By 2016, about 98 percent of Sri Lankan households had access to national grid electricity.

Much of the growth in electrification over the past 20 years was driven by expansion of the central grid. But many Sri Lankans received electricity from small hydropower sites.

Over the past 20 years, two types of entities—Electricity Consumer Societies (ECSs) and small power producers (SPPs)—came into existence to develop these sites, each serving a very different market. ECSs are voluntary community organizations that were created to build, own, operate, and manage individual, run-of-the-river pico- and micro-hydropower projects to supply electricity to rural households in villages that had not yet been connected to the main grid of the national utility (the Ceylon Electricity Board [CEB]).[17]

SPPs were typically owned by private operators. Between 1996 and 2011, private operators developed more than 100 mini and small hydropower sites, most of them larger (up to 10 MW), main grid–connected, mini hydro projects. In contrast to the ECSs, the SPPs were built for the sole purpose of selling electricity at wholesale to the national utility under a standard power purchase agreement. As the SPPs did not make retail sales at the local distribution level, they were not mini grids.

This case study examines only the ECSs. It describes how they came into existence; how they were financed, operated, and regulated; and what happened to their operations and assets after the CEB grid arrived in their villages.

POWERING HOUSEHOLDS BEFORE A VILLAGE IS CONNECTED TO THE MAIN GRID

Between 1997 and 2011, ECSs built more than 260 individual pico- and micro-hydropower projects to serve isolated villages. These “village hydro projects” (VHPs) were small hydropower projects ranging in size from 3 kW to 55 kW of installed generating capacity and serving 20–150 households. The median system produced 7.5 kW and supplied 27 customers, largely within a 3-kilometer radius. It is estimated that ECSs created a total of about 4 MW of installed generating capacity and provided electricity to about 10,000 rural households.[18] In a sample of five VHPs, the unit cost per installed kW of generating capacity ranged from $1,543 to $2,266 in 2011 (Cabraal 2011).

The service and technical service levels of the village-owned hydropower systems were lower than the levels that later became available upon connection with the CEB lines. In the typical village system, each connected household was limited to a maximum demand of 250 watts. Three to five households in each village were allowed to operate refrigerators. Their owners paid an extra fee for the right to connect their refrigerators to the ECS grid. They were required to turn off the refrigerators for two to three hours during the evening peak hours to avoid causing blackouts and brownouts on the ECS system. During daylight off-peak hours, households were allowed to use irons on a rotating basis. For example, if there were three distribution feeder lines connected to the power house of an ECS system, the households on one distribution feeder would be allowed to use irons from 10 A.M. to noon and the households on the second feeder would be allowed to use irons between noon and 2 P.M. This constraint was imposed to avoid blackouts and brownouts caused by aggregated demands that exceeded the system's maximum instantaneous supply capability.

In addition to these restraints on allowed consumption, the ECS systems also operated with lower construction and technical standards. The ECS distribution systems generally relied on wooden poles, not the concrete poles that were standard on the CEB system. The ECSs also had looser targets for frequency variation (50–55 Hertz [Hz]). In contrast, the CEB was required to meet a specification of plus or minus 0.5 Hz. These lower standards, which were imposed by the agency that gave loans and grants to the ECSs (see below), were designed to reduce the ECSs' capital and operating costs.

Public–Private Partnership

The 260 hydro mini grid projects owned and operated by ECSs were the result of two government of Sri Lanka programs supported by the World Bank: the Energy Services Delivery (ESD) project and the Rural Energy for Rural Economic Development (RERED) project. The two programs created credit lines that operated from 1997 to 2012.[19] Loans to ECSs were made by Sri Lankan commercial banks at more favorable terms because they were supported by World Bank credit lines. The credit lines were administered by the government of Sri Lanka, with an interest rate tied to the average weighted deposit rate. In the absence of these credit lines, it is unlikely that the banks, which did not have access to other sources of long-term capital, would have been willing to lend to the ECSs. The credit lines gave the Sri Lankan banks access to a long-term source of capital specifically targeting the ECS. The Administrative Unit, a group within the Development Finance Corporation of Ceylon (DFCC) bank, administered the program. In addition to the credit line, it administered grants from the Global Environment Facility, channeled subsidies from the government of Sri Lanka, and provided extensive technical assistance to the ECS.

A unique feature of the program was the melding of a community's need for electricity with targeted financial incentives for private sector consultants to assist communities in creating ECSs. Selected local consultants received monetary payments if they created ECSs that were able to build and operate VHPs. Under this program, a private consultant (called a *project preparation consultant*), usually an individual or firm with an engineering background, received a payment of $8,000 from the Administrative Unit for each mini grid project. This payment consisted of a down payment of $3,200 upon review of the technical design, $2,400 upon verification of successful installation, and $2,400 after six months of operation. The consultants were thus more than just advisors without any financial stake in the outcome of the project. They had a direct financial interest in creating viable projects and were referred to as "developers" in a number of project documents.

The consultants were required to perform a range of organizational and engineering tasks, including the following:

- identifying viable hydropower sites
- engaging with the community
- helping form ECSs
- helping ECSs obtain financing
- designing, procuring, and installing the project and the necessary distribution facilities, based on guidelines and standards created by the DFCC Bank and financed by the World Bank's ESD and RERED projects
- helping ECSs obtain all required statutory approvals
- training people in the village to operate and maintain the hydro facility (see Cabraal 2011).

To prove that they were competent to perform these tasks, consultants had to demonstrate a minimum level of knowledge and experience in small hydropower generating projects. In granting registration to applicants, the Administration Unit looked for both engineering and social mobilization skills.

Before the two World Bank projects, various NGOs, such as the Intermediate Technology Development Group (ITDG, now known as Practical Action) obtained funding from donors such as Rotary International to build micro-hydropower facilities in a few remote villages. These pioneering projects "proved the concept." Building on these experiences, the World Bank–funded ESD program provided funding and technical assistance to scale up the concept and moved from pure grant funding to semi-commercial financing. Financing was combined with targeted technical assistance provided by mostly private consultants operating under a performance-based incentive system.

Financing

The initial (pre-ESD) village hydropower projects were 100 percent financed by grants. Over time projects were able to obtain financing from about 10 local commercial and regional development banks that had access to a World Bank credit line, which allowed the banks to offer better terms. The credit line demonstrated that commercial banks perceived the projects as financially viable at least for the period of the loan. A 10 kW VHP that served 40 households had an overall cost of about $16,900;[20] later projects were typically funded as follows:

- commercial bank loan: 35 percent
- cofinancing grant from the Global Environmental Fund: 29 percent
- equity from ECS members: 18 percent
- provincial council grant: 18 percent.

The terms of the commercial bank loans are not public because they are in private loan agreements. However, one knowledgeable observer estimated that in 2010 the typical loan had a 16 percent interest rate and a term of four to five years.[21] This rate was considerably lower than the estimated 48 percent that local non-bank lenders were charging rural households at the time. Some of the commercial bank loans were made to the ECS; others were made to individual members of the ECS.

A unique feature of the ECS loans was the use of cross guarantees. Each household was responsible for part of a loan, and households guaranteed one another's payments.

The success of the ECS is attributable largely to four program elements:

- targeted and timely technical assistance from local private consultants, who were paid for results
- access to commercial bank financing, which was supported by a World Bank credit line
- performance-based grants of $400 per kW of installed micro-hydropower capacity, up to a maximum total grant of $20,000
- endorsement of projects by provincial councils and provision of additional grants by the councils, which enhanced their credibility.

Good design does not automatically lead to good outcomes. The overall program greatly benefitted from the competence and diligence of the staff within the DFCC's Administrative Unit. Unlike the private mini grid projects of Cambodia, the ECSs of Sri Lanka were not spontaneous bottom-up projects. They were nurtured projects, created under a well-designed and well-implemented government program that was codesigned and cofinanced by the Sri Lankan government and donors.

DFCC's Administrative Unit established norms for the technical quality of the individual installations. It required that both design and implementation be performed by the registered project preparation consultant. It also mandated that a registered equipment supplier supply equipment and that the equipment be tested at an independent laboratory. Qualified engineers were hired to review whether the required technical specifications were met at the design, installation, and post-installation stages. The Administrative Unit was thus the de facto regulator of technical quality. This practice is common in many countries. The grant-giving agency rather than the national electricity regulator typically assesses the quality of service (at least at the level of input specifications). The rationale is that the grant-giving agency needs to ensure that it is getting value for money.

Tariff Regulation

Many ECSs began operating long before the Public Utilities Commission of Sri Lanka (PUCSL), Sri Lanka's electricity regulator, came into existence, in 2003. However, even after the PUCSL was created, it did not regulate the retail tariffs the ECS charged its members.

Two explanations have been offered as to why PUCSL did not regulate the prices charged by the ECSs. The first is that ECSs were considered captive generation (that is, a form of self supply), which was usually not subject to tariff regulation.

The second is that the monthly payments made by members to the ECS were viewed as membership subscription fees rather than tariff payments. This view is supported by the fact that the “customers” of the ECS are also its “owners,” implying that members would have no incentive to overcharge themselves for the electricity the ECS provides. The government electricity regulator was therefore not needed to protect ECS members from high prices. In fact, the opposite criticism—that ECS membership fees were too low—has been made. Fees covered operating expenses and loan repayments (during the loan period), with no provision for depreciation or a return on invested capital.[22]

Setting tariffs too low is not unique to Sri Lankan ECSs. It seems to be the norm for community-owned pico, micro, and mini grids around the world.[23] These community-owned entities typically charge tariffs that are too low to maintain commercially sustainable operations over the long run. Tariffs that are too low are not a major concern if the distribution assets of the community-owned system are replaced with new distribution assets paid for by a larger national or regional utility when the main grid reaches the village. They are major concern if the system expects to operate over a long period of time, however. In this case, the system needs to create a depreciation fund to pay for future replacements of the assets. Many community-owned systems are unable or unwilling to create such a fund on an ongoing basis.

WHAT HAPPENED AFTER THE MAIN GRID ARRIVED?

Going out of Existence as a Retail Supplier

ECSs flourished between 1997 and 2012. As the main CEB grid expanded rapidly into villages served by them, many of them went out of existence, as many of their members became customers of the CEB.

A 2014 survey by the Energy Forum found that more than 100 ECS disappeared after the CEB grid arrived. When the CEB grid reached a village that had been served by an ECS, about 60 percent of the ECS's members typically became customers of CEB—usually households closer to the center of the village and households that could afford the connection charge of about $50. The 40 percent of households that stayed with the ECS were usually located farther away from the village center. They continued to be supplied by the ECS, because they were not able to afford the higher connection charge necessary to bring CEB distribution lines to their more distant locations. Once the CEB grid arrived, two electricity distribution systems operated in the village for several years.

It is likely that most ECSs will eventually disappear as viable retail electricity suppliers. The total revenue they will receive from a shrinking number of households will be insufficient to pay for their operational expenses, let alone any major repairs, pushing them into a financial death spiral.[24]

There are two strong economic reasons why ECS members chose to switch to the CEB. First, the CEB offered a significantly lower price per kWh. As soon as a village is connected, households in the village can access the CEB's highly subsidized national lifeline tariff,[25] under which any household that consumes 90 kWh or less per month pays $0.017–$0.067 per kWh.[26] This rate is much lower than CEB's estimated cost of supply to rural households of $0.1351 per kWh. In contrast, if villagers continue to take service from the ECS, they pay about $0.25 per kWh.

Second, the CEB offered a higher level of service. It was able to provide electricity 24/7 and without any major restrictions on the household appliances that could be connected. In contrast, ECS members were usually not allowed to use irons or rice cookers in the evening or morning peak hours. They were also not allowed to connect refrigerators, which, if widely used during peak hours, would strain the maximum available capacity of the system and lead to brownouts or blackouts. For a typical 10 kW system serving 40 households, each household was limited to maximum peak consumption of 250 W, which was sufficient to light a home with a few compact fluorescent light bulbs and a small TV or radio. Connecting to CEB distribution lines allowed households to use more appliances without restrictions on the time of their use (UNDP 2012). In one typical system, the average household consumption went from about 50 kWh per month before interconnection to 90 kWh after interconnection (conversation with Wathsala Herath, Energy Forum, October 28, 2017). Given these differences, it should not be surprising that the ECSs went out of existence.

Becoming a Small Power Distributor: A Nonviable Option

Most stakeholders in Sri Lanka do not think that conversion from an isolated community-owned microgrid to a main grid–connected SPD (as happened in Cambodia) is a viable option for an ECS. In order to become an SPD, an ECS would need to become a cooperative (a formal legal entity that can sign contracts) rather than remain an ECS (a community welfare organization). There is no legal barrier to such a conversion. If the conversion takes place, the Electricity Act 2009 states that a cooperative can apply for a distribution license (Clause 9 (3) (d)). It would be relatively easy for an ECS to convert itself into a cooperative under the 1972 Cooperative Societies Law.

Such conversions have not happened in Sri Lanka for at least two economic reasons. First, most ECSs would have to build totally new distribution systems to meet CEB standards. In most cases, the existing distribution systems would have to be replaced rather than upgraded, a change that would be very expensive. Second, even if the investment to build a new distribution system were 100 percent financed from grants, most ECSs would be too small to operate the new system on a commercially viable basis.

Consider the revenues that would be required to operate a commercially viable distribution system in Sri Lanka. Once connected, ECS members (now cooperative members) would expect to pay the same tariffs as similarly situated rural customers of the CEB. In effect, the CEB's retail tariffs would be a de facto cap on any new distribution cooperative.

But it would be commercially impossible for a new distribution cooperative to charge tariffs as low as the subsidized tariffs the CEB currently charges customers who consume 90 kWh or less. The CEB can spread the cost of this subsidy into the tariffs of its other customers; the cooperative would be unable to do so.

Consider the case of a cooperative that has 50 customers, each consuming 60 kWh a month (higher than the average national consumption). Using the CEB's tariffs, the cooperative's gross monthly revenues would be 50 * ([SL Re 2.50 * 30]) + [SL Re 4.85 * 30] + SL Re 60) = SL Re 14,025 (less than $100), where SL Re 2.50 is the per kWh charge for the first 30 kWh of consumption a month, SL Re 4.85 is the per kWh charge for the next 30 kWh of consumption, and SL Re 60 is a monthly fixed charge. This level of revenues would not suffice even to pay the salary of one operational staff member, let alone purchase bulk power. The typical ECS would simply be too small to commercially sustain a distribution cooperative whose members expect to be charged the same retail tariffs the CEB charges rural customers.[27]

In Nepal, where more than 240 small community-owned distribution systems have been created, the rule of thumb is that the distribution system needs to serve at least 200 customers in order to be financially viable (Energypedia 2014). What is the difference between Sri Lanka and Nepal? In Nepal community-owned grid connected distribution systems, called Community Rural Electrification Entities (CREEs), never operated as isolated mini grids. From day 1 they were connected to the grid operated by the government-owned Nepal Electricity Authority (NEA). The CREEs buy bulk power from NEA under subsidized tariffs.[28] They also receive large capital cost subsidies. Initially, the government of Nepal (through NEA) paid 80 percent of the capital costs of the village distribution system. This subsidy was later raised to 90 percent. Under the rules governing the program, NEA is deemed to be the formal owner of the distribution system, and the CREEs pay a small leasing fee to NEA. The CREEs are required to charge their small customers the same tariff NEA charges its grid-connected customers. It appears that the CREEs are financially viable because they have few capital costs, they pay a subsidized bulk tariff to NEA, and their functions are limited to bill collections and low-level maintenance. It does not appear that there is political will or need to replicate such subsidies in Sri Lanka.

Becoming a Main Grid-Connected Small Power Producer

ECSs could also legally become SPPs when the main grid arrives in their village under the existing standardized power purchase agreement (SPPA) regulation. By 2016, however, only three of the more than 250 ECSs had done so. The three projects had installed capacities of 12, 21, and 45 kW. In order to be able to sign the standard power purchase agreement with the CEB, the ECSs were reconstituted as limited liability companies, changing their legal identity from a Village Electricity Consumer Society to a Village Electricity Consumer Company.

Each of the three limited liability companies has three shareholders: the community, the Federation of Electricity Consumer Societies (FECS), and the Energy Forum, a nonprofit organization that, among other things, promotes the adoption of renewable energy and distributed generation (http://www.efsl.lk/). Under the terms of the agreement to create a limited liability company, the community receives about 40 percent of the income from electricity sales to the CEB. These funds go directly into the bank accounts of individual community members. The remaining 60 percent of income is split between the Federation and the Energy Forum. Membership on the board of directors is split among the three shareholders: two directors represent the village consumers, and three directors represent the FECS and the Energy Forum. In day-to-day operations, the FECS provides management know-how, and the Energy Forum provides technical expertise.

The first interconnection of an ECS was for Atheliya, with installed capacity of 45 kW. The total cost of the interconnection was about $35,000. In the first full six months after Atheliya became an SPP, the total income received for sales to the CEB was $11,000. After paying the operator and other operating expenses, the remaining net income was split among 85 individual member accounts.

In a 2016 survey of 200 ECSs, the Energy Forum determined that 110 were no longer operating. It estimates that about 50 of them could become SPPs. To convert conversion successfully, the Energy Forum believes that the following conditions would have to be met:

- Generating capacity must be at least 20 kW.
- The distance between the CEB grid and the ECS powerhouse should be less than 1.5 kilometers in order to minimize the investment required for interconnection.
- The community must demonstrate interest.
- Funding should be available to connect remaining households (if any) to the CEB grid.
- The ECS should have the ability to generate additional funds (through bank loans or new equity) to finance the connection to the CEB grid.

If an ECS terminates its retail supply business and becomes an SPP, it switches to selling its entire output to CEB. Like the more than 100 small privately owned hydropower SPPs, these newly created community-owned SPPs sell to the CEB under a technology-based feed-in tariff. The feed-in tariff is the same for both private and community-owned SPPs. Currently, the CEB buys electricity from both types of SPPs at a price of Sri Lanka (SL) rupees (RE) 17.85 (about $0.12) per kWh in year 1, with an operations and maintenance escalator clause. After 8 years, and again in year 15, the price received by the SPP drops. The SPPs do not receive a separate capacity payment, because they cannot guarantee capacity. On average, privately owned SPPs are considerably larger with installed capacity of 2 MW versus a median installed capacity of 7.5 kW for ECS. The privately owned SPPs generally also have lower average costs of production.

Legal Prerequisite for Becoming an SPP

In order to operate as an SPP, the owner must have the legal authority to sign a standardized power purchase agreement (SPPA) with the CEB. Under Sri Lankan commercial law, as a community social welfare organization, an ECS cannot enter into such a contract. However, it can become a registered village cooperative. Doing so is relatively easy and inexpensive. Once the ECS becomes a cooperative, it has the legal authority under the Cooperatives Act to sign an SPPA with the CEB. The cooperative also has the option of becoming a shareholder in a limited liability company.

Barriers to Conversion At least six barriers appear to prevent more conversions. First, converting requires funding to pay for technical assistance on the legal, economic, and technical issues that need to be resolved for a successful conversion. When the ECSs first came into existence, the World Bank's RERED hired Sri Lankan consultants to provide this expertise. Funding for technical assistance does not seem to be available from other sources.

Second, investment capital is needed to make the conversion. Conversion requires the payment of application fees and the upgrading of the penstock, poles, transformers, and lines to the transformers. It would be difficult, if not impossible, to raise the necessary capital from ECS members.

Third, there has to be agreement on equity shares if the new entity is a limited liability company. In the three conversions that have taken place so far, villagers received 40 percent of the equity 60 percent went to the Federation and the Energy Forum. There are reports that in some of the failed conversions, villagers felt that they were entitled to a larger share of the equity.

Fourth, land ownership and use need to be formalized. When the project operated as an ECS, some ECS members who were landowners informally donated the use of their land for ECS facilities to benefit the welfare of the community. If a cooperative or limited liability company is created, the transfer of ownership or use of the land owned by individual villagers has be undertaken on a formal (that is, legally recognizable) basis. Some SPP conversion projects failed because some villagers were reluctant to sign legally binding sale or leasing agreements for their land.

Fifth, various approvals are required to make the conversion. The SPP must obtain both a provisional approval and an energy permit from the Sustainable Energy Authority.[29] It must obtain a letter of intent to accept the interconnection from the CEB as well as a generation license from the national regulator. In addition, an ECS that wishes to operate as an SPP must obtain an environmental clearance from Sri Lanka's national environmental agency. This clearance takes time because the national environmental agency will usually send the application to its provincial office, and no action can be taken until the provincial environmental office gives its clearance. ECSs that wish to operate as SPPs have complained that the requirements they face from the central environmental authority, the national electricity regulator, and the CEB are the same requirements larger projects must meet and that these soft costs kill the financial viability of many potential conversions.

Sixth, water flows in small streams typically vary widely over the year: flows in the rainy season can be more than 10 times higher than in the dry season. Designs for micro-hydropower for isolated villages typically size the turbine and generator for flows of water that are available 95 percent or more of the year. A designer of a grid-connected hydropower project whose goal is profit maximization will generally choose to build a project with a much larger turbine and generator at the same site, designed to capture the full power available from the much larger flows that occur only for a third of the year or less. Depending on the tariff structure and power purchase agreements signed with the utility off-taker, it may make more sense to remove the small village hydropower project and rebuild a larger one rather than go to the trouble and expense of interconnecting a suboptimally sized project.

Adopting a Different Ownership Model

In theory, two other post-interconnection business options might be available to ECSs. Both involve private investors. The first would involve a complete buyout of the ECS generation facilities by a private entity. Once the buyout occurs, the private entity could presumably make investments to expand the installed capacity of the existing micro-hydropower generator so that it could sell more electricity to the CEB. Government officials in Thailand, which had similar community-owned hydropower facilities, opposed this option. They argued that it would not be fair for a private investor to benefit from facilities that had been financed, at least in part, by government money. The private investor could presumably pay back the government for the earlier grants, but there are no reports that they do so in Thailand. It also appears that the Sustainable Energy Authority will not allow this option. Its board has prohibited ECSs from selling out completely to private individuals or companies.

A second option would be for the ECS to create a joint venture with a private individual or company, forming a partnership with the community. Under Sri Lankan law, ECS members must retain 15 percent of the ownership of the new joint venture, which would have a recognized legal identity so that it would be able to sign SPPAs with the CEB. A major advantage of this option is that the joint venture company would presumably have easier access to financing to improve or expand the existing generating facilities than would a stand-alone community-owned cooperative.

The principal financial incentive for a private investor would be the possibility of selling wholesale power to the CEB under the existing feed-in tariffs. In most instances, the private partner in the joint venture would want to increase the size of the generator in order to be able to sell more wholesale power to the CEB. In many cases, the ECS initially installed generating capacity that probably did not take full advantage of the electricity generating potential of the stream. The benefit to the community of a joint venture is that it would provide access to private capital, professional operations, and maintenance of the generating facilities, and the possibility of a future regular revenue stream that could go to a community welfare organization or individual household stakeholders. To date, no joint ventures by an ECS and a private developer have been created in Sri Lanka. More analysis is required to better understand the legal, economic, and political impediments to creating such joint ventures.

TECHNICAL ASPECTS OF INTERCONNECTION

Even when serving isolated villages, Sri Lanka's mini grids were required to follow stringent technical standards in order to receive grant money under the RERED. The standards were lower than the standards required by the CEB on its distribution facilities, however.

When the main grid arrived, the village hydro system needed to change its mode of operation from one in which the micro-hydropower unit sets its own frequency (through the use of an electronic load controller) to one in which it is synchronized with the national grid (and therefore generating in phase with the national grid). Connection to the national grid requires the addition of relay equipment that ensures that the village hydro system safely connects when electrical conditions are appropriate and quickly disconnects in the event of an electrical disturbance on the main grid. These relays depend on the type and size of generator used. For projects under 100 kW, the most common arrangement in Sri Lanka (and the simplest technically) uses an induction generator with relays that will disconnect in overcurrent, under/over voltage, and under/over frequency conditions.[30] Programmable relays for interconnection of these small projects have been designed and manufactured in Sri Lanka. They are reported to be affordable for a complete set of switchgear.

In addition, interconnection to the grid generally requires the installation of poles, electric lines, and a meter. The three ECSs that have connected to the CEB grid have connected at low voltage (400 V).

Interconnection of micro-hydropower projects requires a load flow study to ensure that the voltages in the CEB network will not be adversely affected by the presence of the new generation source. The CEB charges a discounted price for this load flow study of about $700.

CONCLUDING OBSERVATIONS

The Energy Forum catalyzed the interconnection of three formerly isolated mini grids to the national grid and their conversion to SPPs, working diligently to chart a regulatory and financial path for interconnection. It is unclear whether grid interconnection of formerly isolated mini grids will expand substantially beyond this small number. Most ECSs were abandoned when the CEB grid reached the villages they served, for several reasons:

- The CEB offered lower (highly subsidized) prices and better service (more hours of service, generally without connection limitations on the size of appliances that could receive service).
- With a median size of 27 customers, the ECSs were too small to survive as commercially viable SPDs.
- The distribution facilities were not built to meet CEB standards.
- The ECSs did not have access to sources of financing that would allow them to finance the cost of interconnection equipment and expansion of their generation capacity.
- The regulatory requirements to obtain SPP status were designed for larger generators and were too burdensome for the smaller generators operated by ECSs.
- ECSs were widely viewed as a transitional arrangement that could provide a basic level of grid electricity until the CEB arrived with better service at a lower price.

ENDNOTES

[17]The term *pico hydro* refers to systems up to 10 kW of installed generating capacity. Micro-hydro systems installed generating capacity of 10 kW–100 kW. Mini-hydro systems have installed generating capacity of 100 kW–10 MW.

[18]In contrast, the privately owned mini-hydropower projects (each 10 MW or less) selling to the CEB created more than 240 MW of installed generating capacity by the end of 2011.

[19]For information on the World Bank's involvement, see World Bank (2012).

[20]The $16,900 refers to the cash funding required for the project. In addition, villagers were required to provide about 10 percent of the project's costs in labor and materials (see Subasinghe 2016).

[21]Privately owned SPP projects were able to get better loan terms than ECSs. In 2010 the typical loan term for a privately owned SPP appears to have been an 8-year loan with a 13 percent interest rate and a 1.5-year grace period. Loans to ECSs were perceived as riskier, because they were repaid out of the household savings on energy purchases relative to their preconnection payment. In contrast, private operators were guaranteed a 20-year revenue stream for their electricity sales to the CEB.

[22]There were some exceptions. Initially, many ECSs set their monthly fees high enough to fund sinking or reserve funds, which would be used to pay for major repairs. Over time, however, many of them found it difficult to persuade their members to continue contributing to these funds.

[23]For example, an in-depth survey of mini- and micro-hydro projects [MHPs] in Nepal concluded that "tariffs are set to just recover the operating costs and sometime even just the salary costs. To meet the costs of major repairs, users are asked to contribute additional sums. The tariffs are also lower because having contributed in cash and/or kind for the construction of the MHPs, the communities are unwilling to pay higher tariffs reflecting the real costs" (Kumar and others 2015, 42).

[24]Some of the poles and wires of the distribution system were reportedly salvaged for use elsewhere, but the equipment within the generation powerhouse was left to rot and rust (communication with Wathsala Herala, Energy Forum, October 28, 2017).

[25]In 2015 the CEB's average cost of supply at the rural household level was about $0.151.

[26]Even after adding in the fixed charges paid by the CEB's retail customers in the first three blocks of monthly consumption (0–30, 31–60, and 61–90 kWh), the per unit cost is still considerably lower than the roughly $0.25 per kWh the ECS charged. For example, a customer consuming 30 kWh a month would pay $0.017 per kWh plus $0.067 per kWh in fixed charges per kWh or $0.0237 per kWh versus $0.250 per kWh if the same volume of electricity were acquired from the ECS.

[27]In contrast, the average number of customers served by SPDs in Cambodia is 2,600.

[28]In its 2015 second-generation mini grid rules, Tanzania's national electricity regulator (EWURA) mandated that the national utility sell electricity to SPDs at subsidized bulk supply tariffs. This requirement was eliminated in the third-generation rules, issued in June 2017.

[29]The Sustainable Energy Authority has reportedly decided to streamline the process for ECSs that wish to operate SPPs by requiring just an energy permit application. The rationale for streamlining is presumably that the hydropower facility is already established and operating, so there is no need to apply for provisional approval to study the feasibility of operating it.

[30]Grid-connected micro-hydropower uses either an induction generator or a synchronous generator. For information on the distinction between the two generator types and the impact on interconnection with the grid, see Greacen, Engel, and Quetchenbach (2013).

4

INDONESIA: PIONEERING GRID-INTERCONNECTION OF MICRO-HYDROPOWER MINI GRIDS

Mountainous, remote, island terrain and a supportive policy environment in Indonesia led to the construction of mini grids, including more than 1,300 isolated micro-hydropowered mini grids, which provide electricity to isolated villages (Suryani 2013).[31] Most of these mini grids were funded by government grants and built by local private sector companies, often in partnership with community organizations and assisted by domestic and international NGOs.

The transition from isolated to grid-connected mini grids has been a challenge—but not an impossible one. Nine formerly isolated micro-hydropower mini grids have connected to the national grid (Perusahaan Listrik Negara [PLN]), selling electricity at wholesale to it under government-specified feed-in tariffs. Another 50 mini grids coexist next to the national utility grid. About 150 others were abandoned with the arrival of the main grid.

MINI GRIDS, MICRO-HYDROPOWER, AND RURAL ELECTRIFICATION

Mini grids have played a significant role in Indonesia's electrification, which reached 92.8% of households by June 2017 according to the Ministry of Energy and Mineral Resources, up from 91.2% a year prior (Tsagas 2018). Mini grids feature prominently in two significant rural electrification development programs, the 1000 Island Renewable Energy for Electrification Program (REEP) which targeted 94 PV-diesel hybrid projects across 23 islands in Nusa Tenggara Timor (NTT) region (Reber et al. 2016), and the Indonesia Terang (Bright Indonesia) program launched in 2015 which works to bring electricity to 10,300 villages by 2019 (Minister of Energy and Mineral Resources 2016a).

Thus far, none of the hundreds of Indonesia's solar or wind power mini grids have interconnected with the national grid, but as solar PV prices continue to fall, the business models and policy pioneering efforts of micro-hydropower mini grids that have gone on to a second life as grid-connected projects could pave the way for integration of non-hydro mini grids.

The history of micro-hydropower in Indonesia is rooted in the geography of the country. Thousands of inhabited islands make it prohibitively expensive to provide grid electricity to the entire country. At the same time, mountainous topology and a wet tropical climate create mountain streams suitable for micro-hydropower.

For decades, both the government and NGOs recognized the potential of micro-hydropower mini grids to provide rural electricity at lower cost than alternatives. On the government side, Indonesia's Ministry of Energy and Mineral Resources began developing individual micro-hydropower projects in 1995, with a goal of electrifying remote areas. A decade later, the Ministry of Cooperatives and Small and

Medium Enterprises came on board, funding additional projects, with the main goal of generating rural income. Seven Indonesian ministries have implemented community micro-hydropower projects.

Deployment of village micro-hydropower started in earnest in the mid-1990s. As of 2013, the vast majority (1,033 projects) were funded by the government, often using funds from international donors but managed by an Indonesian ministry. Communities and civil organizations built 199 projects, PLN and other companies built 79, and "other cooperation, partnerships and unknown" accounted for an additional 31 (Fadhilah, Suryani, and Schultz 2013).

In government projects, assets are owned by the local (district or provincial) government, and the project is managed by a local community-based organization. NGO-built projects are owned and operated by community-based organizations. At the village level, a team that generally includes two operators, a director, and a secretary operate average-size projects.

Isolated micro-hydro mini grids in Indonesia vary in capacity from a few kW to hundreds of kW, with most projects in the 5–40 kW range (Suryani 2013). A 2015 study commissioned by the Policy and Operations Evaluation Department of the Netherlands Ministry of Foreign Affairs found that electricity consumption is not metered in most communities with micro-hydropower (Peters and Sievert 2015). Most households pay for electricity based on the type and number of appliances used.

A minority of communities use load limiters (miniature circuit breakers) and base the tariffs on their current rating. Some communities offer special lifeline tariffs for the poorest members. Communities with micro-hydropower typically set their own tariffs, with the aim of covering the costs of operation and maintenance and future repairs. In practice, tariffs are often insufficient to pay for repair services when needed (Peters and Sievert 2015).

Indonesia's burgeoning private micro-hydropower sector industry typically supplies and installs the turbines, generators, and civil works for these projects, as well as equipment to connect micro-hydropower projects to the national grid. Starting in the early 1990s, donor-funded capacity-building programs helped the private sector acquire the skills needed to implement high-quality micro-hydropower projects and provide post-installation services, particularly around the city of Bandung, the capital of West Java (table 4.1).

Good-quality equipment and installations increased the sustainability of many projects, which in turn helped convince the Indonesian government that micro-hydropower was a viable electrification solution for remote villages with suitable water resources. It also made it easier for micro-hydropower associations to lobby for policies that support mini grids and their integration with the grid. Two micro-hydropower associations, Yayasan Mandiri and the Asosiasi Hidro Bandung (AHB), served as focal points for technology innovation and actively lobbied for enabling policies and programs.

Thanks to a combination of technical capacity building, supportive policies, and demand for electricity in remote areas in Indonesia (and abroad), a strong domestic micro-hydropower industry grew. By

TABLE 4.1
Donor Programs for Scaling Micro-Hydropower in Indonesia

PROGRAM	DURATION	FUNDING AGENCY	KEY ASPECTS
Mini Hydro Power Project (MHPP)	1990–96	GTZ	• Developed and introduced technology to NGOs and small-scale equipment manufacturers • Collaborated with ITDG (United Kingdom), Skat Consulting (Switzerland), and FAKT (Germany)
Mini Hydro Power Project (MHPP)	2000–2005/06	GTZ	• Transfered standardized cross-flow turbine designs to local equipment manufacturers • Provided policy assistance to the government to enable small power producers to interconnect and sell power to the national grid
Energising Development Phase I (Endev I)	2006–09	German-Dutch Energy Partnership	• Targeted the development and strengthening of community-based micro-hydropower ownership models and institutional setups • Provided capacity building for community-based micro-hydropower plants constructed by various government and nongovernment programs
Integrated Microhydro Development and Application Program (IMIDAP)	2007–10	Global Environment Facility Trust Fund	• Involved cooperation between the Ministry of Energy and Mineral Resources and UNDP • Developed the capacity of micro-hydropower stakeholders • Developed rural micro-hydropower-based industries and other productive end uses
Energising Development Phase II	2009–12	Multidonor Global Partnership, EnDev	• Technical Support Unit (TSU) provided technical assistance to communities and other stakeholders implementing micro-hydropower projects • Covered more than 140 projects (10–50 kW) in eight provinces
Energising Development Upscaling Phase	2013–18	Multidonor Global Partnership, EnDev	• Supports the government in implementing rural electrification program using micro-hydropower and photovoltaic (PV) technology • Covers 309 micro-hydropower projects (from EnDev Phase II) and 305 PV mini grids

2016 more than 350 specialized engineers, technicians, and project developers were believed to be working on mini grid projects in Indonesia. In addition to meeting local demand, the Indonesian micro-hydropower industry has looked overseas, exporting turbines and control systems to Cameroon, Ethiopia, Germany, the Lao People's Democratic Republic, Madagascar, Malaysia, Mozambique, Nepal, Papua New Guinea, the Philippines, Switzerland, Tanzania, Uganda, the United Kingdom, and Zaire (HYCOM 2017). These companies not only build micro-hydropower turbines and controls, they also manufacture the equipment necessary to connect micro-hydropower project to the grid (box 4.1).

BOX 4.1

Using Local Technology to Connect Micro-Hydropower Projects to the Grid in Indonesia

Indonesian developers use locally built technology to interconnect with the grid. For a three-phrase system, costs range from $5,000 for a 5 kW system to $18,000 for a 100 kW system (table B4.1).

TABLE B4.1

Components of Grid-Connected Micro-Hydropower Projects in Indonesia

COMPONENT	FUNCTION
Electronic load controller or governor	Automatically synchronizes the micro-hydropower frequency with the grid frequency
Generator/grid protection	Disconnects the generator in event of overcurrent, short circuit, earth fault, reverse power, over/under voltage, over/under frequency, rate of change of frequency (optional), or phase unbalance
Automatic voltage regulator	Supports parallel operation of the main and mini grid
Power factor regulator	Adjusts the automatic voltage regulator to maintain the power factor or reactive power; without the power factor regulator, the operator must adjust the voltage of the automatic voltage regulator at each start
Metering	Shows volt/amp/kW/kWh for micro-hydropower and main grid

REGULATIONS FACILITATING GRID INTERCONNECTION

Indonesia's regulations enabling interconnection of mini grids have evolved over many years. The Electricity Law of 1985 established PLN as the country's national utility, with monopoly control over all aspects of the electricity sector. The economic crisis of the late 1990s weakened PLN's financial viability. In response, Indonesia passed the Electricity Law of 2002, which liberalized and allowed for private sector participation in the sector. PLN maintained control of the transmission and distribution system, but both generation and retail sales were opened up to private participation. For a brief period, nationwide retail electricity tariffs were allowed to be market based, and the Electricity Market Supervisory Agency was established to provide independent regulatory oversight.

In 2004 Indonesia's Constitutional Court deemed the 2002 law unconstitutional and ruled that electricity should be delivered exclusively by a state-owned agency. Annulment of the 2002 law essentially reenacted the 1985 law. As a compromise between the 1985 and 2002 laws, the government passed the Electricity Law of 2009, which allowed the private sector to generate and distribute electricity to end-use customers but retained PLN's "right of first priority."

Regulations under the law were generally implemented through ministerial decrees. In 2002, Indonesia adopted Ministerial Decree 1122/K/30/MEM on Small Distributed Power Generation Using Renewable Energy, known by Indonesians as PSK Tersebar. It required PLN to purchase electricity from cooperatives, the private sector, and government company small power producers (SPPs) below 1 MW. It standardized feed-in tariffs based on PLN's location-specific generation costs.

In 2009, a similar decree was issued for projects of 1–10 MW; it gave regional governments a greater role in licensing and allowed for region-specific feed-in tariffs. Critics complained that the decree also increased bureaucratic requirements involved in obtaining a power purchase agreement.

Decrees in 2012, 2014, 2015, and 2016 refined feed-in tariffs based on technology type, years of operation, and the voltage of interconnection; denominated tariffs in U.S. dollars; and established regional concessions (table 4.2). All of the decrees except the 2016 one focused almost entirely on the level and structure of feed-in tariffs.

TABLE 4.2

Policies Affecting Independent Power Producers of Renewable Energy in Indonesia

YEAR	POLICY NUMBER AND NAME	KEY ATTRIBUTES
2002	Ministerial Decree 1122/K/30/MEM: Small Distributed Power Generation Using Renewable Energy (known as PSK Tersebar) (IEA 2002)	• Requires Perusahaan Listrik Negara (PLN) to purchase from cooperative, private, and government small power producers (SPPs) • Covers plants of less than 1 MW • Sets SPP feed-in-tariff set at 80 percent of PLN's location-specific electricity base price for medium voltage (60 percent for low voltage)
2009	Ministerial Decree No. 31/2009: Tariffs for Small and Medium Scale Power Generation Using Renewable Energy and Excess Power (IEA 2009)	• Requires PLN to purchase from small- and medium-scale renewable energy plants up to 10 MW • Sets feed-in tariffs at Rp 656 (about $0.064) per kWh x F if interconnection at medium voltage and Rp 1,004 (about $0.098) per kWh x F at low voltage, where F is a location factor for four regions that ranges between 1.0 (for Bali) and 1.5 (for Papua) • Allows PLN to purchase electricity at cost higher than above-mentioned tariffs based on its Own Estimation (OE) price, subject to approval by Minister of Energy and Mineral Resources • Exempts projects interconnected before 2009
2012	Ministerial Decree No. 4/2012: Electricity Purchase from Small and Medium Renewable Energy and Excess Power (IEA 2012)	• Differentiates tariff levels based on installation type, location, and voltage of grid interconnection • Does not specify how long eligible renewable plants will benefit from introduced tariff
2014	Ministerial Decrees 12/2014 and 22/2014, on mini-hydro feed-in-tariff regulation (Minister of Energy and Mineral Resources, 2014a, 2014b)	• Bases feed-in tariffs on factors in Decree No. 4/2012 plus years of operation and use in Rp per kWh • Includes cost of transmission line between mini grid and PLN grid in feed-in tariff • Sets power purchase agreement without tariff negotiation or price escalation • Establishes detailed mandatory procedure and timelines for development and execution of power purchase agreement

(continued)

TABLE 4.2
Continued

YEAR	POLICY NUMBER AND NAME	KEY ATTRIBUTES
2015	Ministerial Decree No. 19/2015, on mini-hydro feed-in-tariff regulation (Minister of Energy and Mineral Resources 2015)	• Denominates feed-in-tariffs in U.S. cents per kWh • Subjects existing projects to feed-in tariff revisions
2016	Ministerial Decree No. 38/2016, on acceleration of electrification in rural areas by setting up small-scale electric power supply businesses (Minister of Energy and Mineral Resources 2016b) and Ministerial Decree No. 39/2016, on regulation on grid-connecting renewable energy–based mini grid (Minister of Energy and Mineral Resources 2016b)	• Allows private business entities to provide electricity to currently unelectrified regions through geographically based business area concessions • Generation up to 50 MW in capacity allowed per site • Establishes feed-in tariffs for grid-connected renewable energy mini grids
2017	Ministerial (Minister of Energy and Mineral Resources) Decree No. 39/2017. (Minister of Energy and Mineral Resources 2017)	• Allows grid connection of government-funded micro-hydropower projects

WHAT HAPPENED AFTER THE MAIN GRID ARRIVED?

The PLN grid reached about 200 of the estimated 1,300 off-grid micro-hydropower projects in Indonesia. For these projects, four outcomes have been observed:

- **The mini grid was abandoned.** In an estimated 140 cases where the micro-hydropower project did not function well as a stand-alone system (because of lack of proper management, for example) or the tariff was higher than PLN's tariffs, the community abandoned the project, and many village households became customers of PLN.
- **The mini grid continued to operate.** In about 50 cases where the micro-hydropower mini grid worked well and had a lower retail tariff than PLN, the community continued to operate it as a separate mini grid, with its own generation and distribution, while PLN provided electricity using a separate distribution line. Evidence from interviews suggests that whether customers decide to move to PLN lines or remain with the micro-hydropower mini grid depends on the relative quality of service.
- **All output was sold to PLN.** In five cases, the mini grid stopped providing retail service to the village and became a pure SPP that sold all of its generated electricity to PLN.
- **Only excess output was sold to PLN.** In four cases, the micro-hydropower plant continued to operate as a mini grid selling electricity at retail to villagers but sold all excess generation to the PLN for income generation.

The last two outcomes are examples of interconnection successes that Indonesian micro-hydro developers are working to advance.

Selling All Output to the Grid

Five micro-hydropower projects were converted to pure SPPs upon the arrival of the PLN grid (tables 4.3 and 4.4). These projects had capacities of 13–730 kW. In all five cases, grants from international sources funded implementation of the off-grid components. A loan funded the grid-connection equipment for the largest project; the four other projects received funds from international sources under PSK Tersebar. The oldest project, Curugagung (box 4.2), was completed under a

TABLE 4.3

Grid-Interconnected Mini Grid Projects in Indonesia That Started as Stand-Alone Projects, 1991–2006

PROJECT NAME AND REGION	CURUGAGUNG, WEST JAVA	DOMPYONG, JAVA	SELOLIMAN (KALI MORON), JAVA	SANTONG, WEST LAMBOK	SELIDO-KECIL, WEST SUMATRA
Year of interconnection	1991	2003	2003	2004	2005/06
Pre-interconnect village load (kW)	12	10	30	15	730
Average monthly revenue	Rp 1.19 million ($88)	Rp 1.5 million ($110)	Rp 1.4 million ($100)	—	—
Number of connections	121	40	45	—	20
Feed-in capacity (kW)	12	30	30	40	668
Tariff (per kWh)	Rp 112 ($0.008)	Rp 600 ($0.044)	Rp 533 ($0.04)	—	Rp 442 ($0.033)
Voltage	Low	Low	Medium	Low	Medium
Sells all kW or only excess?	All	Excess only	Excess only	Excess only	All
Costs of equipment to interconnect	Rp 90 million ($6,700)	Rp 55 million ($4,100)	RP 50 million ($3,700)	RP 90 million ($6,700)	Rp 140 million ($10,400)
Funding source to interconnect	Loan	GTZ	GTZ	Local government	Equity and bank loan
Project owner	Cooperative	Cooperative	Village association	Village cooperative	Developer
Project facilitator	Yayasan Mandiri	ENTEC and Heksa	ENTEC and Heksa	Renerconsys	PT AMS
Annual income generated from sales to Perusahaan Listrik Negara (PLN)	Rp 10 million ($755)	—	Rp 68 million ($5,040)	—	Rp 2 billion ($148,000)
Uses of income from sales to PLN	Repay micro-hydro-power investment	Fund coopera-tive activities	Fund second hydropower plant downstream from first	—	Owner discretion

Note | — *Not available.*

TABLE 4.4

Grid-Interconnected Mini Grid Projects in Indonesia That Started as Stand-Alone Projects, 2008–13

PROJECT NAME AND REGION	WOT LEMAH MHP, JAVA	KRUENG KALLA MHP, ACEH	CIGANAS MHP, WEST JAVA	BAKUHAU MHP, SUMBA, NTT
Year of interconnection	2008	2010	2012	2013
Pre-interconnect village load (kW)	7.5	40	80	37
Average monthly revenue	Rp 0.9 million ($70)	Rp 4.24 million ($310)	Rp 4.7 million ($350)	Rp 2.2 million ($160)
Number of connections	25	222	485	305
Feed-in capacity (kW)	20	40	100	37
Tariff (per KWh)	Rp 533 ($0.04)	Rp 1,204 ($0.089)	Rp 656 per ($0.049)	Rp 525 ($0.039)
Voltage	Medium	Low	Low	Low
Sells all kW or only excess?	Excess only	All	All	All
Costs of equipment to interconnect	Used interconnection equipment in Seloliman (Kali Moron) project (see table 4.3)	Rp 535 million ($40,000)	Rp 270 million ($20,000)	Rp 140 million ($10,400)
Funding source to interconnect	Village, GIF, PLN	IBEKA	IBEKA	IBEKA
Project owner	Village association	Village cooperative	Village cooperative	Village cooperative
Project facilitator	PT GMN Renerconsys	IBEKA	IBEKA	IBEKA
Annual Income generated from sales to Perusahaan Listrik Negara (PLN)	Rp 61 million ($4,520)	Rp 248 million ($18,400)	Rp 406 million ($30,000)	Rp 180 million ($13,300)
Uses of income from sales to PLN	Improve community livelihood	Provide micro loans, start small shops	Provide micro loans, start small shops	Provide micro loans for all households

BOX 4.2

Curugagung, Indonesia's Pioneer Grid-Connected Micro-Hydropower Project

The owner of the Curugagung project invested all of his savings to develop an off-grid micro-hydropower project. Completed in 1991, with an output of 13 kW, it sold electricity to the 121 households in the village.

Just three years after the project began operations, the PLN grid reached the village. The tariff of the mini grid could not compete with the tariff offered by PLN.

Upon the owners' death, the NGO Yayasan Mandiri successfully lobbied the government to allow the project to interconnect with the PLN grid. Tariffs are low, but the income generated has been sufficient for financial viability.

This one-off arrangement prompted the finalization of PSK Tersebar, which later helped establish the more supportive 2009 regulations. The negotiated feed-in tariff is Rp 112 (about $0.008) per kWh, which yields about Rp 10.2 million ($755) a year, assuming a capacity factor of 0.8. The plant is currently being rehabilitated.

BOX 4.3

The Seloliman Project, an Excess Only Micro-Hydropower Mini Grid

Seloliman was established in 1994 as a 12 kW system. In 1998 it was expanded to a 30 kW system, with support from GTZ, the Global Environment Facility Small Grants Program, and smaller donors. In 2003 the project became the first project to interconnect to the PLN grid under PSK Tersebar. The cost of equipment for grid synchronization was about $6,000. In addition, the project had to pay for technical tests to meet requirements imposed by PLN.

Before interconnection with the main grid, the project charged retail tariffs of Rp 280 ($0.021) per kWh. After interconnection it was able to sell bulk electricity to the PLN main grid at Rp 533 ($0.04) per kWh. In 2010, the project sold 26 percent of its electricity to retail customers, accounting for 16 percent of annual revenues. The remaining 74 percent of electricity was sold to the national grid; it accounted for 84 percent of the projects' revenues (Budiono n.d).

After the project was interconnected to the PLN grid, the association used the income generated to develop a site slightly downstream. Water that exits the Kalimarior project outflow channel enters the intake of the Wat Lemah project, generating electricity that is sold to PLN under the PSK Tersebar program.

regulation that preceded PSK Tersebar and inspired its drafting. Three of the projects were owned by the village cooperative that had managed the micro-hydropower project when it was off-grid. The remaining two were privately owned, one by an individual from the village and the other by a micro-hydropower development company.

Selling Only Excess Electricity to the Grid

Four micro-hydropower projects that were converted to SPPs sell only excess power to PLN (tables 4.3 and 4.4 and box 4.3). All four projects are owned by the village cooperative or association that established them and were interconnected to the PLN grid under PSK Tersebar. They range in capacity from 20 kW to 40 kW.

WHY HAVE SO FEW MICRO-HYDROPOWER PROJECTS BEEN CONVERTED TO SMALL POWER PRODUCERS?

Very few projects been converted to some form of SPPs. In contrast, 300–400 new micro-hydropower projects have started as on-grid facilities. One reason that so few micro-hydropower projects have become SPPs is that a portion of interconnection equipment costs are fixed. Restrictive regulations and policies have also impeded conversion.

Inability to Obtain Permits

Indonesian law states that "grants of State/Regional Property shall be conducted with consideration for social, cultural, religious, humanitarian, noncommercial, and state/regional governmental purposes" (Peraturan Pemerintah No. 27/2014). This law has been interpreted to mean that government-funded infrastructure cannot be used to generate private income. The government classifies SPPs as private or commercial income generation. As such it could provide permits for government-funded isolated micro-hydropower projects that would enable them to be converted to SPPs. Because most micro-hydropower projects implemented before 2009 were funded by the government (though the sources of the funds were international in some programs), most projects were blocked from receiving the required connection permit. For this reason, all of the projects in tables 4.3 and 4.4 have received private or foreign funding.

SPP developers argue that these government-funded micro-hydropower projects should be given permits to become SPPs because PLN sales would be made on behalf of the village cooperative. In cooperative-owned SPPs, all of the income from sales to PLN supports social welfare organizations, such as schools and clinics. Thanks in part to lobbying from SPP developers and micro-hydropower associations, grid connection of government-funded micro-hydropower projects is now allowed, per Ministerial (MEMR) Decree No. 39/2017, passed in May 2017. It will be interesting to see whether this regulatory change leads to substantial increases in grid-connected mini grids in Indonesia.

Inadequate Tariffs for Projects Interconnected before 2009

Before the regulations introduced in 2009, all interconnections to the PLN grid were handled under the PSK Tersebar regulation, which stipulates feed-in tariffs based on the voltage type and location-specific generation costs of PLN. Developers have complained that the stated generation costs that PLN announced lacked transparency and were unreasonably low in some cases. As a result, few micro-hydropower projects became SPPs before 2009. The 2009 regulations did not allow SPPs established before 2009 to qualify for new feed-in tariffs. Ministerial (MEMR) Decree No. 39/2017 specifies a 20-year power purchase agreement at tariffs of Rp 500 ($0.037) per kW for micro-hydropower.

Expense of Complying with Post-2009 Regulations

The 2009 and 2012 regulations provide higher feed-in tariffs, but they also require procedures that are complicated and expensive. For this reason, most cooperatives and NGOs continue to use PSK Tersebar, despite its low tariffs and transparency shortcomings.

CONCLUDING OBSERVATIONS

When the grid arrived, most micro-hydropower projects in Indonesia were abandoned. But an important precedent was set in two important connection modalities: Five projects connected as SPPs and sell electricity to the national grid, and four projects continued to sell electricity to retail customers and interconnected as SPPs to sell excess electricity to the national grid. These projects pioneered the regulatory environment and technical procedures, allowing others to follow in their footsteps.

Indonesia's micro-hydropower sector is well positioned for grid interconnection in several ways:

- Indonesia pays feed-in tariffs to grid-connected projects that are, in theory, based on the geographically specific costs of electricity. These tariffs create economic niches in which grid-connecting formerly isolated micro-hydropower plants are profitable.
- Indonesia developed a sophisticated micro-hydropower industry over the course of two decades, thanks in part to long-running training programs supported by donors. Competition and local expertise reduce costs for good-quality installations. This pool of expertise includes spillovers from larger (MW-scale) hydropower projects built as independent power producers designed to be connected to the grid from the outset.
- A 2017 ministerial decree allows government-funded projects (by far the largest category of project) to interconnect and sell electricity back to PLN. The impacts of this decision have yet to be felt but are likely to increase the number of projects that survive the arrival of the grid through interconnection. Hurdles remain, however. Feed-in tariffs remain low. Low tariffs compound another key problem: financing. Donor grants have completely covered the interconnection costs of nearly all formerly isolated micro-hydropower mini grids that have gone on to connect to the grid. For the sector to advance, developers and finance intuitions will need to work together to enhance the ability of financial institutions to evaluate the risk and profitability of these projects—and enhance developers' ability to deliver projects with acceptable risk and returns. Financial institutions will need to offer financial products on terms that match the revenue stream and risk profile of these projects.

ENDNOTE

[31]GIZ, the German aid agency, has prepared an online interactive map of both hydro and solar mini grids that it helped to finance (see http://remap-indonesia.org/).

5

CONCLUDING OBSERVATIONS AND EMERGING DEVELOPMENTS

The case studies of Cambodia, Sri Lanka, and Indonesia demonstrate several approaches to what happens when the national grid arrives in areas previously served by mini grids. They vary from interconnecting the mini grid generator to the main grid and selling electricity at wholesale to the national grid (small power purchasers [SPPs] in Sri Lanka and Indonesia) to transitioning to small power distributors (SPD) and abandoning backup generation (in Cambodia) to hybrid cases in which the mini grid both sells wholesale electricity and maintains its own distribution network to continue making retail sales in the village (SPP plus retail sales in Indonesia). In Sri Lanka and Indonesia, the most common outcome, by a wide margin, was abandonment.

The core case studies indicate that various post-interconnection business models can be commercially viable. They are more likely to succeed when the following conditions are in place:

- Interconnection costs are not prohibitively high.
- Interconnection with formerly isolated mini grids does not present significant engineering or operational challenges, because the mini grids were built to stringent technical standards.
- The isolated mini grid systems have access to additional sources of financing.

Analysis of the case study countries reveals some patterns. As grid interconnection of formerly isolated mini grids becomes more common, technology and other factors evolve, and understanding deepens, some outcomes may no longer be viable and other new options may emerge.

OPTIONS FOR MINI GRIDS WHEN THE MAIN GRID ARRIVES

Stop Selling Self-Generated Electricity Directly to Retail Customers

When the main grid reaches a village that had been served by a community-owned mini grid, most mini grids stop selling self-generated electricity directly to retail customers. All of the community-owned hydro mini and microgrids in Sri Lanka and many (but not all) in Indonesia stopped serving households.

In Cambodia the outcome was different. Many private mini grid operators continued to sell to retail customers, but they did so as distribution entities that resell electricity generated by larger distant power plants owned by the main grid operator rather than continuing to sell power from their own small diesel generators.

Four main factors may explain why community-owned mini grids exit from retail supply business:

- differences between the higher tariffs often charged by the mini grid and the lower tariffs usually charged main grid
- differences in service levels between mini grids and the main grid

- legal and financing barriers
- the degree to which key local stakeholders depend on the mini grid for their livelihood.

Differences in Tariffs National or main grid operators (usually government-owned enterprises) generally charge tariffs that are well below a mini grid's cost of service. If the service quality of the main grid is similar or better, it is not surprising that customers switch to the national grid when it arrives. National grid tariffs are often artificially low because of highly subsidized lifeline tariffs for low-consumption customers and politically mandated national uniform tariffs. A uniform national tariff reflects the government's decision that customers in rural areas should pay the same price for electricity as urban customers, even if the cost of serving rural customers is much higher than the tariff charged. The tariffs of national utilities are also often artificially low if the government provides general subsidies to government-owned utilities through the forgiveness of interest and principal payments or the government provides the government-owned utility with the opportunity to purchase fuel at subsidized prices.

Indonesia is an exception. The tariffs for rural customers of Perusahaan Listrik Negara (PLN) on some remote islands, where PLN relies on diesel-fired generators, are often higher than the tariffs hydropower-based community-owned mini grids charge their members on the same islands. In about 50 cases, when the PLN grid reached villages on islands that would be served by PLN's high-cost diesel generation, the community-owned mini grids continued to serve most members because their prices were lower than PLN's tariffs. In some instances, wealthier families migrated to PLN because it was able to support larger household electrical loads than the mini grid.

Differences in Service Levels The national grid can generally power larger household loads during peak consumption periods. The mini grid's generating capacity is often sufficient in the first few years before households acquire more and larger appliances. Once they do, customers are disappointed to find that they are unable to run them during peak evening hours because too much electrical demand on the mini grid's system triggers blackouts and brownouts. If the national or regional grid operator is able to provide reliable service during peak hours, mini grid customers will probably switch over to the national utility.

However, the national utility may not be able to provide reliable service during peak hours for various reasons. In many developing countries, insufficient generating or transmission capacity is often a problem for larger national or regional government-owned utilities. The national or regional grid may be overtaxed, or there may be insufficient generating capacity connected to the grid, especially during the evening peak load. In Uttar Pradesh (India), there is a surplus of grid-connected generation, but the state government-owned distribution utilities do not have the money to pay for the available electricity. Although on paper a government-owned utility offers 24/7 service, its actual performance often falls far short of that promise, for both physical and financial reasons.

Legal Restrictions Sri Lanka's national electricity law prohibits mini grids from making retail sales once the main grid arrives. The national utility (the Ceylon Electricity Board [CEB]) holds a legal monopoly on the right to sell electricity directly to retail customers. Isolated micro-hydropower mini grids were able to get around this restriction by registering as nonprofit Electricity Consumer Societies (ECSs), which then claimed that they were not selling electricity but rather supplying electricity to their dues paying members.

Once the village is connected to the CEB grid, the CEB requires that the ECS stop supplying electricity to its members (there was no legal restriction on the ECS becoming an SPP and selling electricity at wholesale to CEB if the ECS was legally reconstituted as a cooperative). A similar legal restriction exists in Bangladesh for solar-powered mini grids, the dominant technology for mini grids there. Once the national grid arrives in a community served by a privately owned mini grid, the mini grid is required to shut down its retail business and become an SPP that sells exclusively at wholesale to the national utility (Castalia Strategic Advisors forthcoming b). In Bangladesh and Sri Lanka, two of the five coexistence options described in section 1—the SPD option and the SPP + SPD option—are thus unavailable.

Sri Lanka also restricts wholesale sales of electricity by ECSs. In order to interconnect and sell wholesale electricity to the CEB, ECSs must become cooperatives. As ECSs, they lack the legal identity to enter into contracts. If they become cooperatives, they can sell to the CEB under the CEB's standardized power purchase agreement contract. Few ECSs have pursued this legal option because of difficulties in obtaining financing and lack of technical know-how about how to implement the conversion.

One plausible alternative would be to form a joint venture with one of the private developers that has experience selling bulk power to the CEB. The private developer is likely to have easier access to and receive better terms on loans from commercial banks because it has demonstrated experience in operating larger hydropower-based facilities. For an ECS (or a successor cooperative), a potential benefit of a joint venture is that it can create a steady stream of dividends from future bulk power sales which could be used by individual households or the cooperative for projects that benefit the community. No such joint ventures have been formed in Sri Lanka.

Laws and policies conceived to reduce corruption have sometimes had the unintended effect of blocking grid interconnection for community-owned mini grids. In Indonesia the government reportedly does not give interconnection permits to projects built with government funds because of concerns that private operators would use village electricity infrastructure facilities paid for with government grants for private gain.

A similar phenomenon has been observed in Thailand, where community micro-hydropower projects were built as joint ventures in which villages provided labor and local materials and the government provided the mechanical and electrical hardware. This arrangement worked smoothly as long as the villages were isolated from the main grid. The village cooperative was prohibited from selling electricity to the national utility, however, by anti-corruption regulations that ban the sale of government assets to private interests and forbid government property from being used to produce revenues for private groups (such as the village micro-hydropower cooperative or a joint venture between the village cooperative and a private operator). One village micro-hydro project commissioned all necessary interconnection equipment but has been mothballed because of the provisions of this law. Subsequent projects were abandoned rather than attempting to interconnect (Greacen 2010).

Clear and legal transfer of ownership from the government to the village cooperative upon commissioning would help, as would flexibility in interpreting corruption rules. For example, micro-hydropower projects built with government assistance should be allowed to interconnect to the main grid if they pay the government a royalty for use of government assets or reimburse the government for the grants it provided to construct the isolated mini grid. Such an arrangement could yield a win-win outcome: the government would receive some repayment for its earlier grants, and the villages would benefit from additional revenues through bulk sales to the main grid operator.

Livelihood Motivations The main purpose of community-owned systems, especially systems funded by substantial government or donor grants, is to supply the community with electricity. The sale of electricity from the mini grid does not provide a major source of income for the community. If the main grid arrives, bringing an alternative means of providing lower cost electricity, the community will usually have little incentive to keep the mini grid running.

In Cambodia, private operators rely on mini grids for some or all of their livelihoods. With the arrival of the grid threatening their businesses and rendering their assets stranded, private operators were strongly incentivized to adopt the SPD business model, which allowed them to continue making sales with their existing distribution assets.

Become a Small Power Producer

The fact that most isolated community-owned mini grids stop making retail sales does not necessarily mean that they will become grid-connected SPPs. The transition from isolated mini grid to grid-connected SPP for pioneers has not been easy, but it has paved the way for interconnection of future projects.

In Indonesia, nine mini grids made the transition, and 150 were abandoned. In Sri Lanka, three mini grids connected to the main grid as SPPs, and more than 100 were abandoned. The interconnection of these 12 projects would almost certainly not have happened were it not for the involvement of NGOs in each country that pushed for changes in national-level policy and the development of regulatory frameworks that allowed for interconnection. These pioneers paved the way for future interconnection projects, opening up options that will be available to community-owned mini grids going forward.

Even if legal and policy barriers to interconnecting are overcome, there is no guarantee the new arrangement will be profitable, however. Selling electricity to the national utility often means accepting a low feed-in tariff (typically the utility's avoided generating cost from very large power plants). In Indonesia, for example, the formerly isolated 30 kW Seloliman micro-hydropower project sells electricity to the national utility at about $0.05 per kWh. The roughly $9,700 a year it earns barely covers operational expenses, taxes, land lease, and royalty payments for water usage.

Where multiple parties come together to arrange for interconnection, the question arises of how to split the earnings from the sale of electricity. In Sri Lanka, the three mini grids that did connect were limited liability companies with three shareholders: the community, the Federation of Electricity Consumer Societies (FECS), and the Energy Forum, a nonprofit organization. Under the terms of the agreement, the community receives about 40 percent of the income from electricity sales to the CEB, and the remaining 60 percent of income is split between the Federation and the Energy Forum. One Sri Lankan micro hydro developer expressed the opinion that 40 percent is too low a share to be attractive to communities.

Embrace the Transition from Mini Grid to Small Power Distributor

In most countries with community-owned mini grids, the arrival of the main grid has led to customers shifting over to the national utility. Cambodia's experience has been different. Nearly 28 percent of Cambodia's retail electricity is now sold through about 250 SPDs, most of which were previously isolated mini grids.[32] The SPDs provide electricity to more than 1.15 million customers (EAC 2018). This local private sector–led approach reflects three factors:

- the national utility's lack of funds and interest in investing in order to reach retail customers
- a proactive government and regulatory authority that worked with mini grid developers to upgrade distribution networks to utility standards before interconnection and adopted licensing and capital cost subsidy programs that help mini grids transition to SPDs
- the willingness of the national government to provide SPDs with ongoing operational subsidies as the quid pro quo for the requirement that they sell electricity to retail customers at a uniform standard national tariff that does not recover their costs.

FACTORS AFFECTING INTERCONNECTION OUTCOMES

Technology, scale, and historical context play important roles in determining outcomes when the main grid arrives to an area served by an isolated mini grid. The post-connection business model affects the cost of interconnection, and wholesale tariffs affect the viability of grid-interconnected mini grids.

Technology

Mini grids that connected to the main grid appear to fall into two major groups. The first includes hydropower mini grids that sell electricity to the national grid as SPPs (Sri Lanka and Indonesia). The second includes diesel mini grids in the hundreds of kW range that have hundreds or even thousands of customers that abandon their diesels and connect to the main grid as SPDs (Cambodia).

Local private sector actors (businesses or community cooperatives) are able to create value in both groups. In Sri Lanka and Indonesia, they did so by operating local hydropower plants as SPPs. In Cambodia they did by maintaining the distribution system and coordinating sales to hundreds or thousands of small retail customers.

In Sri Lanka and Indonesia, hydropower was able to survive the transition to a grid-connected business model even with low wholesale feed-in tariffs, thanks to zero fuel costs; 24-hour electricity; long plant lifetimes; and technical, legal, and managerial assistance from NGOs. The lack of examples of grid interconnection of formerly isolated mini grids that use other generating technologies (solar, biomass gasifier) suggests that the higher generation cost of those fuel sources creates additional hurdles that make an already marginal business proposition even less likely to work.

Solar-powered mini grid assets are also more movable than hydro-powered mini grids. Hydro-powered equipment is generally engineered for a specific site, and much of it is set in concrete. In contrast, solar arrays and associated equipment powering solar mini grids can be unbolted, trucked to a new unelectrified location, and reassembled. Given that many mini grids are now solar powered, more research is needed on the economics of grid interconnection versus relocation for solar hybrid mini grids.

Hydro-powered mini grids are rare in Cambodia because much of the country is flat. Isolated mini grids were powered mostly by relatively inexpensive diesel generators that used expensive fuel. In these cases, the distribution system ends up being the long-lived asset, with value that can be leveraged by experienced local mini grid operators in a post-connection environment. Compared with the high cost of diesel, grid electricity distributed and resold through SPDs was inexpensive, providing sufficient margin for distributors to both charge lower tariffs and earn a profit.

Scale

Distribution franchisees in Cambodia serve an average of 2,300 customers. At substantially smaller scales, the regulatory burden of overseeing multiple private sector actors is too high. In Sri Lanka, the community-owned mini grids had too few customers to support a commercially viable, stand-alone distribution system. In Indonesia the scale of grid-connected projects is typically greater than 100 kW. Smaller projects have been connected in Sri Lanka, but their interconnection has been made possible largely through the dedicated efforts of the Energy Forum, an NGO for which commercial profitability has not been a high priority.

Country Context

Private diesel mini grids emerged in Cambodia mainly because the government and national utility were unable to provide service to many rural areas. Enterprising locals recognized the strong demand for electricity. Rural people were willing to pay more than $1 per kWh for mini grid electricity. Many of these local enterprises had unregulated prices because they came into existence before the national electricity regulator (the Electricity Authority of Cambodia [EAC]) was created in 2002. This commercial partnership was an uneasy one, with tariffs that were determined through a constant negotiation and discussion between buyers and sellers. Mini grid operators benefitted from the fact that the EAC took a light-handed approach to mini grid tariff regulation in its early years, focusing on incentivizing mini grids to improve the quality of their distribution facilities through the "carrot" of longer license terms.

With the mini grid distribution infrastructure in place, it made sense to the government and the regulator to encourage mini grids to transition to distribution franchisees, with assistance from the World Bank. Doing so allowed the national utility to serve more people more quickly by focusing on the construction and operation of medium-voltage lines, leaving the distribution side to experienced and nimble mini grid operators who knew their local communities well.

In Sri Lanka, micro-hydropower mini grids connected to the main grid resulted largely from efforts of the renewable energy NGO Energy Forum, which recognized that the plants had substantial life left. Without its actions, it is likely that all mini grids would have been abandoned with the arrival of the main grid.

In Indonesia micro-hydropower was brought up to high technical levels of proficiency through long-term assistance from international development partners led by GIZ, in collaboration with Skat Consulting, the Intermediate Technology Development Group (ITDG), and FAKT Consulting. Local counterparts developed skills in micro-hydropower design, construction, and operations and maintenance. These trained professionals soon developed collaborations with key ministries and utilities.

Post-Connection Business Model

Different post-connection business models require different interconnection investments (table 5.1). Interconnections costs also vary by distance to the grid, the voltage level at which the interconnection will be made, and whether the equipment is domestically available.[33]

The conversion to an SPD requires the lowest interconnection investment. Once distribution lines are upgraded to utility standards (required by the Cambodian regulator for a long-term mini grid license even before interconnection), interconnection is straightforward, requiring a step-down transformer, standard distribution switchgear, and a meter at the point of interconnection.

TABLE 5.1

Equipment Requirements of Post-Interconnection Business Models

EQUIPMENT	MAIN GRID PURCHASES ASSETS AND TAKES OVER	MINI GRID OPERATOR BECOMES A SMALL POWER DISTRIBUTOR (SPD)	MINI GRID OPERATOR BECOMES A SMALL POWER PRODUCER (SPP)	SPP AND SPD (NO ISLANDING)[a]	SPP AND SPD (INTENTIONAL ISLANDING)
Distribution grid to grid standards	✓	✓		✓	✓
Transformer, distribution switchgear, and meter		✓	✓	✓	✓
Relays supporting synchronous operation with the grid[b, c]			✓	✓	✓
Electronic load controller[d]			Recommended	Recommended	✓

a. Appendix B describes the technical requirements for the SPP and SPD cases, with and without islanding.

b. Generation sources such as photovoltaics that use grid-intertie inverters are simplest to interconnect because their anti-islanding circuits are built in. Most micro-hydropower and biomass/biogas generators use some kind of rotating generation, in which electricity is generated by generators that rotate magnets past sets of copper wire coils. The simplest interconnection of rotating generation is for induction generators. At a minimum, they require relays with the following functions: American National Standards Institute (ANSI) device 81 (over/under frequency), ANSI 59/28 (over/under voltage), and ANSI 51 (overcurrent). Synchronous generators require ANSI 25 (sync check) in addition to the functions above. Three-phase generators may require neutral voltage displacement (59N) or zero sequence overvoltage relay (59G). Some utilities require additional relays, and developers may choose additional relays to provide further protection to their generators. For more information, see Greacen, Engel, and Quetchenbach (2013).

c. The cost of interconnection relays, step-up transformers, on-grid lines, and transaction meter equipment for the Kalimaron micro-hydropower project in Indonesia was about $6,000 (based on the 2003 exchange rate). An additional $750 was spent on technical tests to verify safety upon commissioning (see Budiono 2017).

d. An electronic load controller is an electronic device, generally used with micro-hydropower, which enables the mini grid to regulate its own frequency. Internal combustion engines (using fuel from biomass gasifiers, biogas, or diesel) typically use a governor to modulate fuel delivery to achieve the same function.

The conversion to an SPP or SPP + SPD requires the interconnecting of a generator to the national grid, which in turn requires the installation of relays that disconnect the generator in the event of a disturbance on the main grid. The most complicated and most expensive are systems that have the ability to connect to the main grid and switch instantaneously to an island mode, providing backup power to local customers. Innovation in grid-interconnection hardware for distributed generation is ongoing, suggesting that costs will fall over the next several years.

Distributed generators that connect to the main grid may also require engineering studies before interconnection. These studies typically cover load flow,[34] faults,[35] and protection coordination.[36] All of these studies begin with a computer model of the existing electricity supply infrastructure (generation, transmission, and distribution) on the main grid and model the impact of adding a distributed generator. Taken together they can help accommodate safe incorporation of mini grids into the national grid and proactively address problems that might reduce the reliability of the grid. These studies can also be useful in preventing conditions under which the mini grid's generator would have to disconnect from the main grid.

Wholesale Tariffs

For an isolated mini grid, the central (and usually only) tariff concern is the retail tariffs that will be charged. But as soon the mini grid is connected to the main grid, the mini grid is likely to be a buyer or seller of other services in addition to its retail sales, including the following:

- sale of bulk electricity to the main grid operator or other entities connected to the main grid (feed-in tariffs)
- purchase of bulk electricity from the main grid or others connected to the main grid (bulk supply tariffs)
- usage charges if the mini grid uses the facilities of the main grid (distribution grid user charges)
- ancillary services (for example, frequency and voltage support) to the main grid operator.

The tariffs charged for these services need to be fair to all parties and reflect a reasonable assessment of the value of the electrical services provided. Regulatory agencies will need to remain vigilant to ensure that main grid utilities do not exploit their monopoly and monopsony powers to charge high prices for the services they provide the mini grid or pay too little for the electricity and services provided by the mini grid.

WHAT IS LIKELY TO HAPPEN IN OTHER COUNTRIES WHEN THE MAIN GRID ARRIVES?

In two of the case study countries (Sri Lanka and Indonesia), most mini grids owned and operated by communities went out of existence when the main grid arrived. In a small number of cases, the mini grids became SPPs selling at wholesale to the main grid. In contrast, in Cambodia many diesel mini grids connected as SPDs.

It is tempting to generalize from these three cases. Doing so would be a mistake, however. Interconnection to the national grid by formerly isolated rural mini grids depends on a complex mix of factors, including technology, the regulatory framework, the ownership model, access to finance, and the tariffs charged by the national utility. In many countries, most of these factors are moving in a direction that is favorable to mini grids.

Certain technical, economic, and regulatory characteristics of mini grids in Indonesia and Sri Lanka made post-connection operation difficult to sustain. The mini grids were generally small, generating only modest revenues. The generation technology used in these micro-hydropower projects required costly modifications and upgrades to accommodate synchronization with the national grid (see appendix B).

The regulatory framework in Sri Lanka and Indonesia was also initially unfavorable. In Indonesia regulations until May 2017 prohibited mini grids that used government funds from interconnecting as SPPs. The ownership model had implications as well. Community-owned mini grids in Sri Lanka and Indonesia had difficulty accessing the credit needed to make necessary investments because they lacked collateral and a conventional business track record. Pioneers opened the door for the possibility of grid interconnection.

Community-owned mini grids in Sri Lanka and Indonesia had difficulty accessing the credit needed to make necessary investments because they lacked collateral and a conventional business track record. The path of least resistance was for community mini grid owners and cooperative decision makers to return to their primary occupations (generally farming) rather than embark on the risky and not particularly profitable venture of converting to a business that would sell electricity to the grid.

The next generation of mini grids in Sub-Saharan Africa and Asia, which can be described as the third generation of mini grids (see appendix C for a discussion of the differences between first, second, and third generation mini grids), will differ from the Sri Lanka and Indonesia cases in four important ways that will influence post–main grid connection outcomes.

First, the new generation of Sub-Saharan African and Asian mini grids is likely to be dominated by modular solar hybrid mini grids in which solar production is backed up by batteries and diesel generators. In many cases, the ability to synchronize with the grid is built in as a functionality of the inverters used; many distribution networks are built grid ready. Grid interconnection economics may be less favorable for solar mini grids than technologies such as hydro, which can generate 24 hours a day. Where grid interconnection does not make financial sense, the modular nature of these technologies allows for their assets to be redeployed in villages outside the expanding national grid network.

Second, most new mini grids will be owned and operated by private investors (international companies, national or local private companies, or combinations of the two). The Cambodia case study suggests that private investors will have a stronger incentive than community-owned mini grids to continue owning and operating at least the distribution components of their assets after the main grid arrives. Observation of community cooperatives suggests that they may take longer than private companies to reach decisions.

Third, governments are increasingly adopting mini grid–friendly regulatory frameworks that increase certainty and provide clear pathways for the arrival of the grid. The risky pioneering of grid-connected mini grids in an uncertain policy and regulatory environment will become a thing of the past.

Fourth, some third-generation mini grids are likely to come into existence through public–private partnerships (PPPs). They are likely to include a contractual agreement between the lead government agency (or utility) and the private developer that addresses what happens when the main grid arrives (see appendix D for a description of Sub-Saharan African PPPs involving mini grids). In Sri Lanka and Indonesia, there was no prior agreement as to what happens when the main grid arrives.

RECOMMENDATIONS

Several policy recommendations and recommendations for future research emerge from the analysis. Policy recommendations include the following:

- **Support a range of electrification options.** Create a regulatory and policy framework that provides incentives for the development of an ecosystem of rural electrification options ranging from solar home systems to mini grids to the national grid. Support the option that makes the most sense in each area, and accommodate the dynamic evolution of this ecosystem over time. Ensure that the policy and legal framework allows mini grids to operate as stand-alone systems or integrate with the national grid. Such a framework would reduce the commercial risk that mini grid developers face in building isolated systems.
- **Support a range of post-interconnection business options.** Offer a range of post-interconnection business options for what happens "when the big grid reaches the little grid." They should include continuing business as an SPP, becoming an SPD, and buying electricity from and selling it to the main grid operator and other entities connected to the main grid (retail plus SPP).[37]
- **Determine compensation for "buy out."** Create rules that specify how mini grid developers will be compensated for their assets if the main grid arrives and the mini grid operator shuts down its business. Consider whether the mini grid operator deserves compensation for its work in "pre-electrifying" the area in addition to compensation for its assets.
- **Streamline regulatory requirements.** Streamline regulatory processes and requirements so that licensing, permission to interconnect to the main grid operator, retail tariff-setting, and other business and environmental approvals are integrated and duplication of bureaucratic processes minimized. Establish lighter requirements for smaller mini grids.
- **Establish interconnection technical standards.** Specify the conditions under which mini grids should be built to grid-ready standards and the conditions under which less costly "skinny-grids" should be allowed.
- **Facilitate joint ventures.** Remove legal and regulatory barriers that prevent communities from entering into joint ventures with private developers for new or expanded mini grids, whether isolated from or connected to the main grid.
- **Create parity for capital cost subsidies.** If capital and operating subsidies are provided to the main grid owner for grid extension and for operating their own mini grids in rural areas, provide comparable subsidies to private mini grid operators for capital costs so that the playing field is level. In general, operating cost subsidies should not be provided to mini grid operators because it would create a heavy and probably unsustainable financial burden on governments. Moreover, operating subsidies should not be needed if mini grid operators have explicit authority to charge tariffs above the national tariff.

These recommendations are not new. National- or state-level regulators in India, Nigeria, Rwanda, and Tanzania have already implemented variants of them. In the second half of 2018, the Global Facility on Mini Grids expects to issue a six-country study (of Bangladesh, Cambodia, India, Kenya, Nigeria, and

Tanzania) that will compare and contrast how regulators have dealt with these and other regulatory issues.

In light of the limited scope of this study, and the likely emergence of third-generation mini grids, further research with a strong operational focus should be undertaken. These studies could focus on the following:

- **Main grid–connected mini grids.** Examine how mini grids can be connected (in islanded and non-islanded mode) to the main grid from day 1 of operations (as proposed by PowerGen in Kenya and in the recently issued Nigerian mini grid regulations) or upon later connection.[38] In the United States and other developed countries, connected mini grids have been proposed that could provide grid services to the main grid such as "storing energy when it's cheap, providing energy when it's expensive, serving as backup capacity, or smoothing out frequency and voltage fluctuations" (Roberts and Chang 2018). With good pricing incentives such as time differentiated tariffs, it is conceivable that the new third generation of mini grids in developing countries could provide similar services.
- **Interconnecting of solar hybrid mini grids.** Analyze the commercial, technical, and regulatory issues in interconnecting solar hybrid mini grids to the main grid.
- **Magnitude of existing subsidies.** Provide estimates of the magnitudes of existing capital and operational subsidies in countries that are promoting mini grids and main grid extension. These include:
  - general subsidies to publicly owned national and regional entities that provide distribution service
  - specific subsidies for the connection of new rural customers through main grid extension by publicly owned national and regional distribution
  - specific subsidies to publicly owned national and regional entities that own and operate isolated mini grids.
- **Regulatory contracts for mini grids.** Describe, compare, and evaluate the regulatory contracts developed in Bangladesh, Haiti, Mali, Myanmar, Nigeria, and other countries (see appendix E).
- **Competitive procurements for mini grids.** Describe, compare, and evaluate competitive procurements for mini grids in Nigeria, Sierra Leone, Uganda, and Zambia.
- **Benchmarking of hard and soft costs.** Develop a cross-country database on the "hard" and "soft" costs of interconnection as they vary by technology, distance to the main grid, interconnection voltage levels, and the functions performed by the mini grid.
- **Commercial viability spreadsheet.** Create a spreadsheet template that can be used to calculate the costs and revenues of interconnecting previously isolated mini grids from the commercial perspectives of the mini grid owner and the main utility owner.
- **Primer for non-engineers.** Develop a primer for non-engineers on the engineering aspects of interconnection and different levels of islanding.

ENDNOTES

[32]In 2014, the national grid sold 2,958 GWh to retail customers and distribution franchisees sold 1,128 GWh (EAC 2015).

[33]The ESMAP Global Facility on Mini Grids has initiated a project to systematically collect cost data on different types of mini grids. It plans to expand the database to include data on the costs of interconnections for different voltages, distances, and post-interconnection business models. In a separate effort, the International Finance Corporation has collected data on operating costs, capital costs, and revenues for a sample of 20 privately owned mini grid companies operating in 12 developing countries. See IFC (2017).

[34]Load flow studies focus on the flow of electric power in the network with and without the distributed generator, to determine whether the normal operating range of the distributed generator will cause problems with excess or inadequate voltage at various locations in the grid over the grid's expected variations in consumer load.

[35]Fault, or short circuit, studies investigate how the electricity network will respond to short circuits at various locations with the addition of the distributed generator. They seek to identify whether the current supplied by the distributed generator at the moment a short circuit occurs will create new safety hazards and if so what measures are needed to mitigate the new hazards.

[36]Protection coordination studies investigate how various protection elements in the grid network (relays, breakers, fuses) function together with the addition of the distributed generator and suggest adjustments to the threshold and timing settings of these devices.

[37]This recommendation is similar to a recent recommendation of the African Mini Grid Developers Association (http://africamda.org).

[38]This issue is important for India, where most of the 300 million unelectrified households live in villages that are already connected to the main grid (see Palit 2016).

APPENDIX A | DIFFERENCES BETWEEN MICROGRIDS AND MINI GRIDS

The term *microgrid* is used in the United States and other high-income countries. The term of choice in low-income countries is *mini grid*. The two terms refer to electrical installations that typically differ in several ways. The principal differences are as follows:

- **Connected versus nonconnected.** In the United States, most microgrids are connected to the main grid from day 1 and are also able to operate in island mode. Most of the time, they operate in main grid–connected mode. In Asia and Sub-Saharan Africa, most mini grids begin operations as isolated systems with no connection to the main grid. In Sub-Saharan Africa, very few mini grids have connected to the main grid. Asia has had more experience connecting mini grids to the main grid. In many cases (in China and Cambodia, for example), the mini grids go out of existence as mini grids. As seen in the Indonesia and Sri Lanka cases, a small number becomes small power producer (SPPs). Once they do, they are no longer mini grids, because they no longer sell electricity to households and individuals within their villages.
- **Different customers**, **different motivations.** Many of the estimated 1,900 operating or planned microgrids in the United States were built to serve individual customers. About a third serve a single institutional or university customer. Another 15 percent supply military installations (Aram 2017).[39] These customers receive electricity from the main grid. They connect to mini grids in order to ensure electricity supply if the main grid goes down. In the northeastern United States, state and local governments have pushed for the installation of mini grids that supply electricity to key government services (such as hospitals and police and fire stations), so that they continue to function if the main grid goes down (as the result of a storm or a cyberattack, for example). Most mini grids in Sub-Saharan Africa and Asia were built to provide access to a beginning level of grid-quality electricity to isolated communities. They are usually[40] built in communities that are not likely to be connected to the main grid within the next few years. Their customers are households and small businesses in the villages.
- **Individually designed or modular.** In the United States, many microgrids were built as "one-off" projects that were individually designed. In Sub-Saharan Africa and Asia, the dominant mini grid technology will probably be a modular solar hybrid generation system that can be easily scaled up as electricity demand increases.[41] Over time, it is likely that microgrids in OECD countries and mini grids in low-income countries will use the same (or essentially the same) makes and models of inverters with the same capabilities for remote monitoring and operating in parallel with other equipment to allow scaling. For this hybrid solar technology, it is likely that there will be increasing convergence between developed and developing countries over time.

- **Fuel sources.** In the United States, natural gas and the waste heat from co-generation facilities provide the main fuel sources for microgrids. In Asia and Sub-Saharan Africa, the main fuel sources are diesel and hydro, with rapid expected growth in solar PVs.
- **Communication systems.** In the United States, microgrids usually communicate through sophisticated real-time communication systems with the system operators of the main grids. In Asia and Sub-Saharan Africa, most mini grids are isolated. Initially, they have no need to communicate with the main grid. But in some instances, they may communicate through the Internet, continuously conveying monitored information on electrical parameters (voltage, frequency, and so forth) and electricity sales (kWh). The nature of the post-connection communication system will depend on the post-connection business model selected by the mini grid.

ENDNOTES

[39]The remaining customer groups are remote villages in Alaska and elsewhere (25 percent), utility distribution systems (12 percent), critical government installations in communities (9 percent), and commercial and industrial installations (7 percent).

[40]Even in low-income countries some mini grids are installed in villages already connected to the main grid. In the Indian state of Uttar Pradesh, for example, OMC Power installed mini grids in grid-connected villages to serve customers who want a more reliable supply of electricity than the government-owned distribution company was able to supply. Unlike the microgrids in the United States, the OMC mini grids operate side by side rather than connected to the main grid.

[41]One example is ABB's new MGS100 product. See https://www.youtube.com/watch?v=I-RL5Ap63Qg.

APPENDIX B | SHORT TECHNICAL PRIMER ON MAIN GRID-CONNECTED MINI GRIDS

In some locales, mini grids are permitted to sell electricity to households and the main grid.[42] This appendix describes the technical requirements they must meet to do so.

Selling electricity to the main grid (whether or not the mini grid is simultaneously supplying its own customers) requires two key changes to a mini grid that had been operating as a stand-alone facility. The first has to do with the control of frequency—how rapidly the generator is spinning and thus how quickly the electricity is alternating. When the village needs more electricity, the generator in a stand-alone mini grid needs to ramp up power production; when the village needs less electricity, it needs to reduce power production. Failing to match supply and demand results in generators spinning either too slowly or too rapidly, producing electricity with frequency that is too low (when demand exceeds supply) or too high (when supply exceeds demand). Either can result in burned-out appliances and/or burned-out generator parts.

Stand-alone fossil fuel generators (such as diesel generators) match supply and demand by automatically modulating the amount of fuel sent to the engine through a governor that controls fuel injection or the engine's carburetor. More fuel means more power, enabling the generator to keep on spinning at a rated speed even as the generator demands more torque, like a bicyclist exerting more effort to maintain speed going up a hill.

Small hydropower mini grids use a similar technique. An automatic regulator device carefully closes or opens the penstock valve little by little in response to real-time changes in electricity demand. Most plants below 100 kW opt for a solution that is simpler to implement because it requires no moving parts. A circuit called an electronic load controller diverts a portion of the electricity to a ballast load (a heater) to be "thrown away"—literally burning up any excess electricity as heat. This discarded electricity is adjusted many times a second in order to keep the generator spinning at the correct speed in the face of varying loads. A bicycle analogy would be the (exhausting) practice of pedaling at full power all the time but keeping the speed constant by applying the brakes—sometimes more, sometimes less depending on the terrain.

MINI GRIDS CONNECTED TO THE MAIN GRID

When a mini grid's generator connects to the national grid, it no longer needs to vary its power production in response to demand; the national grid is able to absorb all of the electricity provided to it by the mini grid generator, as the contribution is miniscule in comparison to the main grid's generators. Somewhere in the national grid's large collection of interconnected generators, the function of balancing supply and demand is accomplished—typically by large fossil fuel or hydropower generators that are dispatched as needed by the system controller, at least one of which is always operating in a "load-following" mode, modulating fuel or water supply in real time as necessary.

The first change that is needed to transition from stand-alone to grid-connected mode is thus to switch from a mode in which the generator controls the frequency to one in which the generator power output is constant. In the case of a micro-hydropower plant with an electronic load controller, the electronic load controller is turned off in grid-connected mode. There is no need to waste any excess, as the grid can absorb it all.

The second change that is needed is the addition of protection relays that monitor the voltage and frequency of the main grid and monitor the power flowing from the mini grid to the main grid. If electricity voltage or flows are sufficiently abnormal, these relays disconnect the small distributed generator to protect both it and the main grid. One of these relays also handles the tricky business of waiting until the moment when the generator's frequency and phase are in perfect lockstep with the grid before closing the switch that connects the two during initial start-up or any reconnection following a disconnection.

The way the generator regulates voltage may also need to change, depending on the requirements of the utility. When operating as a stand-alone mini grid, the generator's automatic voltage regulator is set to keep voltage constant. The national utility may prefer a different setting—for example, one in which the power factor is constant, which may be useful in enhancing the utility's ability to control voltage in different nodes in proximity to the distributed generator. (A full explanation is beyond the scope of this appendix.)

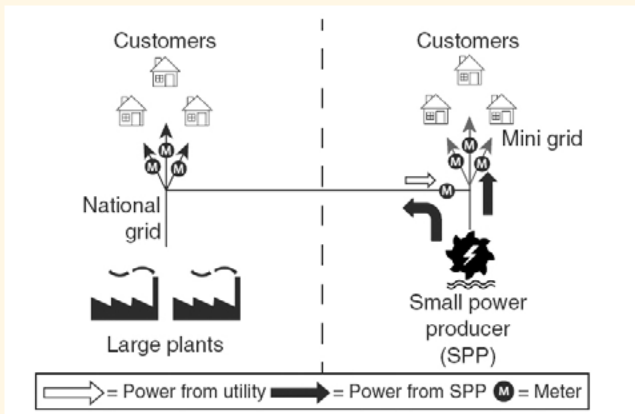
SELLING TO BOTH MAIN GRID AND MINI GRID CUSTOMERS

What are the requirements of a system that supplies power to village households and sells excess electricity to the main grid? In the simplest case, the village load never exceeds the generator's capacity, and power always flows out of the mini grid to the national grid—the situation in the Indonesian case study.

To understand what is going on, conceptualize the mini grid and its connected retail customers as a single electrical entity, with the mini grid bundle connected to the national grid through an electrical meter at a single point. Sometimes (for example, in the middle of the night) this entity produces more electricity for the national grid because villagers are asleep and using less power. At other times (for example, in the evening, when villagers are using lights and watching TV) the mini grid produces less electricity for the grid. From the national grid's perspective, the mini grid looks like a generator that ramps up and down. The grid absorbs whatever is provided because overall balancing of supply and demand is accomplished elsewhere in the national grid. Because the national grid is establishing frequency, power flow out of the mini grid system is always simply the excess—nothing more, nothing less.

FIGURE B.1

Schematic of Mini Grid Supplying Electricity to Its Own Customers and Selling Excess to the National Grid



Source | *Tenenbaum and others 2014.*

Note | *If the generator always produces more electricity than the community of retail customers uses, there is no flow of power from the utility.*

SELLING TO AND BUYING FROM THE MAIN GRID

In the more complicated situation in which power flows into or from the mini grid, the main grid experiences the mini grid sometimes as a power source (the curved black arrow in figure B.1) and sometimes as a load (the hollow arrow). In this case, the utility typically requires a more complicated metering arrangement because it (justifiably) may want to charge more for the backup electricity it supplies than it charges for the varying amounts of electricity the mini grid injects into the main grid.

ISLANDING

The situation gets trickier still if the mini grid wishes to maintain the ability to continue serving its customers in the event the main grid suddenly shuts off. This situation—called *intentional islanding*—requires instantly disconnecting from the de-energized national grid and turning on the electronic load controller (in the case of micro-hydropower) or the speed governor (in the case of an internal combustion engine) to perform the function of frequency control that the grid had been providing while interconnected.[43] Utilities are more anxious about islanding because substantial safety hazards arise if utility lines are energized by the mini grid when utility workers think the lines have been de-energized. Examples of mini grids with intentional islanding capability are not uncommon.[44] The practice is likely to become more common as deployment of mini grids, and their interface with often intermittent national grids, expands.

A spectrum of grid resiliency exists (Lavoie 2018). At one end are customers with no resiliency. They will experience full loss of power when there is a power outage on the main grid.

Next are customers who can transfer some or all of their loads to a backup mini grid generator that is turned on when the main grid's power goes out. These customers will experience a loss of power for the length of time it takes to turn on the mini grid generator and for the generator's voltage and frequency to stabilize, typically at least 30 seconds.[45] For certain critical loads (such as data servers or medical equipment), an integrated uninterruptible power supply can sustain continuity of supply that can easily cover the transition period to backup power operation.

The next level of resiliency is an uninterrupted transition to islanded operation during power outages so that customers experience no interruption in service for critical loads. The highest level of resiliency accomplishes uninterrupted transition for all customers' loads. These levels of resiliency might be needed for medical facilities, research facilities, or manufacturing, where loss of power can cause substantial losses of product or information. Accomplishing these levels of resiliency presents an engineering challenge that is more difficult and costly to accomplish, as sufficient long-term generation needs to be available immediately, with a switchover occurring within milliseconds of loss of power. A key component to enable this transition is a microgrid control that can sense disturbances and transfer power quickly to an alternate source. Because sources that use rotating generation (fossil fuel generators, hydropower, biomass, and so forth) cannot come up to speed this quickly, these generators must be in operation continuously in order to be prepared in the eventuality of a national grid outage or have battery storage and fast-acting inverters to convert stored DC electricity to AC needed by loads.

Rural villages in developing countries do not need the level of resiliency that a data center in California requires. One would therefore expect mini grids in developing countries to be built with levels of resiliency at the first or second levels.

What level of grid resiliency do the mini grids discussed in this report provide? The answer varies considerably from country to country and mini grid to mini grid. In Cambodia, the mini grids that transitioned to distribution franchisees ceased operation of their diesel generation and removed and resold this generation equipment. Their customers are at the low end of the resiliency spectrum: their lights go dark in a national grid power outage and stay dark until the main grid comes back up. Grid-connected hydro-powered mini grids in Indonesia, as well as the 4 MW Mwenga hydropower plants in Tanzania, have the ability to operate in an islanded mode. But transition to and from islanded operation requires a system restart that takes several minutes.

With minimal or no engineering adjustments, many third-generation solar or solar/battery/diesel hybrid mini grids have the ability to transition very quickly (without noticeable loss of power) to island mode from grid-connected mode and vice versa, thanks to features that are built into their inverters. Whether companies will choose to keep solar/battery/hybrid mini grids installed when the main grid arrives remains an unanswered question. These mini grids have high generation costs (making sales to the national grid generally unattractive), and their batteries degrade even when they are not being cycled (making it costly to keep them in place as backup). In the absence of customers willing to pay a premium for backup power, some third-generation mini grid developers may seek other escape routes when the main grid arrives, such as building their equipment into shipping containers that can easily be removed and redeployed to other villages where the national grid remains far away.

The ability to intentionally island is one step toward a future that microgrid engineers in the United States and Europe are developing. Advanced microgrids will include controllers that will be capable of sensing main grid conditions, monitoring and controlling the operation of a microgrid and its loads to maintain electricity delivery to critical loads during all operating modes (grid-connected, islanded, and transition between the two) (see Sandia National Laboratories 2014, Venkata and Shahidehpour 2017). Further refinements include the ability to connect mini grids to form regionally networked microgrids and automating the ability of mini grids to provide energy and ancillary services (such as reactive power). If incentivized and coordinated, all of these refinements can enhance the operational performance, reliability, security, and economics of both microgrids and the main grid.

ENDNOTES

[42]This business model, which exists in Indonesia, is explicitly allowed for in the 2016 Uttar Pradesh (India) Mini Grid Renewable Energy Generation and Supply Regulations, which allow mini grids to sell excess/surplus electricity to the distribution licensee at the interconnection point at the applicable feed-in tariff.

[43]In India the technical interconnection rules of the Central Electricity Authority and the draft national mini grid policy do not allow for intentional islanding by connected mini grids (CEA 2013).

[44]The Mwenga hydropower project (http://www.riftvalleyenergy.com/projects/mwenga-hydro/) and TPC (http://www.alteogroup.com/company/tpc-limited) are two examples of grid-connected mini grids with islanding capability in Tanzania. Intentional islanding is a feature of most microgrids built in countries in the Organisation for Economic Co-operation and Development (OECD). This feature is fairly common in off-the-shelf grid-ready stand-alone inverters.

[45]A variation on this level of resiliency is the secure power supply (SPS) outlet feature of SMA-brand TL series inverters for grid-tied rooftop solar electric systems. In the event of a power outage, the operator can transfer appliances to a dedicated outlet that provides up to 1,500 or 2,000 watts of power when the sun is shining. Limited backup power is available without a separate backup generator or battery storage. For a technical document describing this feature, see SMA (2013).

APPENDIX C | THREE GENERATIONS OF MINI GRIDS

FIRST- AND SECOND-GENERATION MINI GRIDS

Mini grids are not a new phenomenon. More than 100 years ago, they were the starting point for electrification in many countries, including China, Sweden, the United Kingdom, and the United States.[46] In the early stages of electrification, when there was no central grid in these countries, mini grids were often the building blocks for what later became the interconnected central or main grid. These early facilities can be thought of as the first generation of mini grids. As the main grid spread, mini grids were either integrated into the main grid or went out of existence. These early mini grids experienced many of the regulatory and organizational issues faced by mini grids in developing countries in Africa and Asia today.

Second-generation mini grids—the subject of this report—are found mostly in low-income countries. Unlike the earlier mini grids, these mini grids were built to fill the empty, mostly rural, spaces that have not yet been reached by the main grid or to serve areas where it would be too costly to extend the main grid. Local communities and local entrepreneurs typically built and operated these mini grids. When the main grid reaches them, they usually go out of existence or transform themselves into small power producers (if using a renewable energy rather than diesel) or small power distributors.

THIRD-GENERATION MINI GRIDS

Many large international and national private companies are taking initial steps to develop mini grid projects. International electrical equipment supply companies, including ABB, Caterpillar, General Electric, Siemens, Tesla, and others, have announced that they intend to enter the mini grid market. It is still unclear whether they will limit themselves to their traditional role of supplying equipment or will also take on operational and ownership responsibilities. These companies are currently building pilot projects with new modular technologies (usually solar photovoltaic [PV] with some backup or storage system) in a number of developing countries. These large private companies are presumably motivated by the potential to build hundreds or thousands of installations using their proprietary technologies. Building hundreds of modular systems would create opportunities for cost-reducing economies of scale that were not available to second-generation developers. Operators of third-generation mini grids will have easier access to national and international financial markets than did the local entrepreneurs who owned and operated second-generation mini grids.

Second-generation mini grid developers almost always use standard existing technologies (mini-hydropower and diesel generation). They typically charge customers flat monthly tariffs or postpaid tariffs, relying on basic meters, on-site meter reading, and in-person collections.

In contrast, third-generation developers use sophisticated hybrid generating technologies, such as modular solar PV combined with batteries and diesel generation, optimized with state-of-the-art control systems. Most developers use prepaid payment systems similar to the ones developed for mobile phones and some solar home systems in Sub-Saharan Africa. Third-generation mini grids also make use of cellular data networks to allow remote monitoring of the generation system, so that engineers can spot problems as they emerge and make adjustments or repairs before small problems cascade into larger ones. Some third-generation mini grid developers use sophisticated load dispatch technologies to ensure that priority loads always get electricity by automatically shifting low-priority loads to times of energy surplus.

ENDNOTE

[46] Analysis of the role of mini grids in the development of power systems in these countries is the subject of a forthcoming ESMAP report, entitled A Retrospective Analysis of the Role of Isolated Mini Grids in Power System Development.

APPENDIX D | PUBLIC–PRIVATE PARTNERSHIPS FOR MINI GRIDS IN KENYA, NIGERIA, AND SIERRA LEONE

Several Sub-Saharan African countries are exploring the use of public–private partnerships (PPPs) to promote mini grids. A PPP is a "contract between a private party and a government agency, for providing a public asset or service, in which the private party bears significant risk and management responsibility" (World Bank 2012, 11). This definition encompasses both mini grid developers that provide new assets and services and mini grid developers that provide service on existing assets. It includes mini grid developers whose services are paid entirely by their customers and mini grid developers that receive some or all of their payments from the government.

Under the PPP approaches being used or proposed in Sub-Saharan Africa, governments usually select their private partners through competitive bidding. The government issues tenders that seek formal bids for the construction and operation of mini grids at one or more locations. The specific commercial rights awarded to winning private bidders differs across countries. This appendix describes the differences in the mini grid PPP projects in Kenya, Nigeria, and Sierra Leone.

Kenya, Nigeria, and Sierra Leone are planning to use top-down competitive procurements for mini grids at specified sites. In all three countries, the rural electrification agencies or ministries of energy will select the sites after gathering social and economic information on the target villages. The governments in all three countries have decided to solicit bids from private companies for packages of multiple villages rather than separate bids on individual villages. In all three countries, the winning bidders will receive capital cost grants from the government.

That is where the similarities end. The three countries made different decisions about who will build, own, and operate the generation and distribution components of the mini grid and who will sell electricity to households and businesses.[47] The three business models are described below.

KENYA: ENGINEERING, PROCUREMENT, AND CONSTRUCTION (EPC) CONTRACTOR AND TRANSITIONAL MINI GRID OPERATOR

The Kenya Power and Lighting Company (KPLC)—the national distribution company, in which Kenya's national government has a controlling ownership interest—will eventually own an estimated 120 new mini grids in 14 northern counties. KPLC, rather than the mini grid developer, will make all retail sales to households that will be connected to these newly constructed mini grids (IDA 2017). Rural households that are customers of the new mini grids will pay the same retail tariffs as any other existing retail customers on the KPLC main grid. As KPLC's uniform national retail tariff is not likely to cover the operating costs of serving customers on these new mini grids, the revenue shortfall will have to be covered through cross-subsidies from KPLC's other customers.

If KPLC is the official supplier of new mini grid customers, what will private developers do? The winning private developers will build, own, and operate the mini grid's generating plant for 7–10 years. They will sell electricity produced by their generating plants to KPLC under a standard power purchase agreement. The developers will also construct and maintain the mini grid's distribution facilities and handle billing and collections for retail sales for 7–10 years as an agent of KPLC. At the end of this period, KPLC is expected to take over ownership and operations. KPLC will be the sole electricity retailer in the village right from day 1, even though it will not initially own the mini grid's generation facilities or operate the mini grid's distribution facilities.

NIGERIA: OWNER AND OPERATOR OF MINI GRID GENERATION AND DISTRIBUTION FACILITIES

A very different approach is under discussion in Nigeria. Mini grid developers, whether selected through a proposed one-time competitive procurement for 250 mini grids or through unsolicited proposals, will own and operate both the mini grid's generation and distribution facilities, an arrangement known as build-own-operate (BOO). The mini grid developer will not receive a long-term legal guarantee of exclusivity from the national government, as typically found in a traditional concession or licensing agreement, however. Instead, the developer's right to exclusivity will be limited to a 12-month development period. This exclusive development period is granted not by the national government but by the community, which may choose to extend it to allow the development to complete project development work. Once the mini grid project becomes operational, however, the mini grid developer has no long-term guarantee from the regulator or the Rural Electrification Agency that it will be able to continue as the owner and operator of the isolated (unconnected) mini grid.

Once the mini grid is connected to the main grid, the developer is basically limited to two post-connection business options:

- If the main grid arrives within five years after the mini grid becomes operational and the mini grid has obtained a permit from the regulator (as opposed to simply registering its existence with the regulator), the developer has the right to financial compensation under a compensation formula specified by the Nigerian Electricity Regulatory Commission for both its distribution assets and 12 months of lost revenue.
- If the developer is able to reach a new agreement with the village and with the distribution company that has connected the village to its grid, it can convert to an interconnected mini grid with the right to buy and sell electricity (as a small power producer [SPP] or as a combined SPP and small power distributor [SPD]).

Nigeria illustrates a common approach to licensing and concessions of mini grids. Like most national governments, the Nigerian government is reluctant to grant long-term exclusive licenses or concessions to mini grid developers, for two reasons. First, it may already have granted exclusive service rights to the same geographic area to a national or regional company. Therefore, it would be of questionable legality to grant a long-term exclusive licenses to a second entity to operate in the same geographic area.

Second, granting such a license to a mini grid could be politically risky. Giving a mini grid developer an exclusive long-term license or concession to serve a village would seem to imply that this village is off limits for connection to the main grid for the duration of the mini grid license or concession. Villagers could easily interpret the concession as indicating that the government views them as second-class consumers.

Faced with these two constraints, one legal and the other political, most governments have opted to grant mini grid developers the right to provide electricity service until the main grid arrives. When it does, the mini grid's rights are limited to whatever exit or coexistence options have been specified in previously issued regulatory rules.

SIERRA LEONE: LONG-TERM OWNER OF GENERATION AND LONG-TERM OPERATOR OF DISTRIBUTION

Sierra Leone is seeking bids from private developers to establish solar mini grids in about 90 villages and towns. The villages and towns will be divided into four regional bidding packages, each containing about 20–25 villages and towns. The four packages will contain two types of mini grids: (a) 54 existing but as yet not operational small mini grids built for the government by the United Nations Office of Project Services (UNOPS) , with money from bilateral donors and (b) about 40 larger greenfield mini grids, whose capital costs will be financed by both the government, with funds from bilateral donors, and the winning private developers.

With the exception of customer meters (which will be installed by the winning bidders), the distribution facilities of the new mini grids will be built by UNOPS, with funding from international donors. Once built, the distribution facilities will be owned by the government of Sierra Leone but operated by the winning bidders. Successful bidders will be required to build the mini grid's generation facilities. They will also be responsible for all new connections and marketing to new customers. The successful bidders will pay a small leasing or usage fee for the right to use the government-owned distribution facilities. Each private developer will have an exclusive distribution license awarded by the national electricity regulator for 10 or more years. It is expected that the regulator will issue a single license to each winning bidder that gives the bidder the right to operate all the mini grids in the package that it won. Ownership of each mini grid's generation and distribution assets will be split between the private developer and the government, an arrangement known as the split asset model.

FEATURES OF THE THREE BUSINESS MODELS

The three business models define how the government answered four basic questions: who builds, who owns, who operates, and who sells. Table D.1 summarizes the three approaches.

TABLE D.1

Business Models for Top-Down Competitive Bidding for Mini Grids in Kenya, Nigeria, and Sierra Leone

COUNTRY	WHO BUILDS?	WHO OWNS?	WHO OPERATES?	WHO SELLS?
Kenya	Generation and distribution: Private developer	Generation: Private developer Distribution: National utility (Kenya Power and Lighting Company [KPLC])	Private developer for 7–10 years as agent of KPLC, after which KPLC owns	KPLC
Nigeria	Generation and distribution: Private developer	Generation and distribution: Private developer	Generation and distribution: Private developer	Private developer
Sierra Leone	Generation: Private developer Distribution: United Nations Office of Project Services (UNOPS) for the government	Generation: Private developer Distribution: Government	Generation and distribution: Private developer	Private developer

The three business models allocate the risk between governments and developers differently. All else equal, developers may be more attracted to models in which there is a clear exit strategy, complete with compensated transfer of assets to a government entity or utility after a prescribed period of time. Conversations with developers reveal that some favor models in which they are not required to invest in, own, or maintain distribution networks, whereas others want to get into distribution and retail supply in order to acquire customer electricity consumption data and be able to sell other services, such as Internet services and movie streaming. All of these decisions affect how much risk each party bears.[48]

The attractiveness of each of these markets depends on many factors that private sector companies will need to investigate in the field before bidding. They include the renewable energy resources present, the price of fuel, the challenges and taxes involved in importing equipment, the likelihood that the village will quickly scale up demand to profitable levels, the load pattern and how it matches the site's hourly renewable energy resource profile, opportunities for recourse if the project does not proceed as planned, and the ease of doing business in the country or region. As these bidding-oriented business models are at embryonic stages, it will fall upon future research efforts to understand which factors attracted private sector investment, which failed to do so, and why.

ENDNOTES

[47]For a more complete and nuanced discussion of mini grid business models, see Knuckles (2016).

[48]A good description of the different types of risk faced by a main grid-connected mini-hydro project can be found in appendix E in Tenenbaum and others (2014). Although the focus there is on grid-connected SPPs, many of the same risks would be present in mini grid projects.

APPENDIX E | REGULATORY CONTRACTS AND MINI GRIDS

In the three case studies described in this report, government policies and regulations were created when particular issues arose. Creating policies and regulations on an ad hoc basis, as the need arises, is not a viable approach for governments in Sub-Saharan Africa and Asia that are serious about encouraging large private investors to build hundreds or thousands of new mini grids. Private investors, especially large national and international companies, will generally not be willing to make major investments in mini grids if there is no policy and regulatory clarity as to what prices they will be allowed to charge and what their post-interconnection business options will be.[49] Without more certainty, most large companies will find investments in mini grids to be too risky.[50] Governments can provide such certainty by issuing national mini grid regulatory policies, by promoting regulatory contracts, or both. Doing so would lay the groundwork for scaled up third-generation (see appendix C) mini grid investment and deployment.

NATIONAL REGULATORY POLICIES

Several countries in Sub-Saharan Africa and Asia have created national regulatory policies for mini grids in recent years. In Nigeria, Rwanda, Sierra Leone, and Tanzania, the national electricity regulators have issued detailed rules and regulations covering retail tariff setting and post-interconnection options for mini grid projects. Draft mini grid rules are expected soon in Kenya. The Indian state of Uttar Pradesh issued both a mini grid policy statement and supporting regulations in 2016 (without the same level of certainty on post-interconnection business options for mini grids). Similar initiatives are under way to introduce mini grid policies and regulations in Bihar and Jammu and Kashmir.

REGULATORY CONTRACTS

In Sub-Saharan Africa, the Caribbean, and Asia, "regulatory contracts" are buttressing national mini grid policies or regulations or, where policies and regulations do not exist, serving as the country's entire regulatory framework. Parties to these contracts include the mini grid developer/operator and one or more of the following: the community served by the mini grid or a local government authority with jurisdiction over the area where the mini grid will operate, the government (typically a ministry), or a utility. A regulatory contract can supplement or substitute for the traditional regulatory approach of relying on the case-by-case application of general principles or standards in mini grid rules or laws. These contracts typically go into more site-specific detail than is possible in a national mini grid regulatory framework. It is not always obvious that the contracts include regulatory functions, because they may have titles such as "Implementation Agreement" or "Subsidy Agreement." But embedded within the contracts are provisions dealing with traditional regulatory decisions relating to tariff setting, quality of service (both the technical and commercial dimensions), and exclusivity. These contractual agreements do not typically address how to handle the arrival of the national grid, an event usually dealt within national mini grid regulations.

Regulatory contracts can create a formal legal commitment from the local government or village organization, which helps ensure political buy-in. Such buy-in is especially important if a mini grid will be charging retail prices that are higher than the tariffs charged by the government-owned utility. Rural villages lack the time and expertise to draft such a contract. If the drafting is left up to the developer, the contract will inevitably be one sided in favor of the developer. Use of a model agreement (as done in Nigeria) is likely to produce a more balanced result.

Regulatory contracts for mini grids are in place or are being developed in several countries. They can take various forms:

- **Contract between a private mini grid developer and a grant-giving agency.** This type of bilateral agreement (used in Bangladesh and Mali) usually performs two functions: it specifies the terms and conditions for receiving and disbursing grants and the terms of the service and the tariffs the developer will be allowed to charge. It is usually used if there is no national regulatory entity or the regulatory entity has exempted mini grids below a specified size from its purview. A principal motivation for the agreement is that the grant-giving agency wants to ensure that it is getting value for money and that mini grid customers are not being exploited. The local government or village organization is a not a signatory to the contract. For an example from Mali, see AMADER (n.d.).
- **Contract between a private developer, a grant-giving agency, and a Village Electricity Committee.** Myanmar is developing a tripartite agreement called the Mini Grid Subsidy Agreement. It will specify retail tariffs, which will be determined by mutual agreement between the private developer and the community, with review and approval by the grant-giving agency. National regulations also under development will address what happens when the national utility arrives. The agreement will apply to mini grid projects that receive capital cost subsidies. Capital subsidies of up to 60 percent will be granted on a first come, first served basis to projects that meet cost and quality thresholds and are located at least 10 miles from the national grid.
- **Contract between a private developer and a community.** The Nigerian Electricity Regulatory Commission (NERC) developed an 11-page contract template that provides a model bilateral contract for mini grid developers and communities in Nigeria that are not connected to the grid (NERC 2017). The distribution company that already has a license to serve the community is not a formal signatory to the contract. But under NERC's 2017 rules, the distribution company must confirm that the community is not in its five-year plan to expand service in its license area or give written consent to the developer to build in a community that is in the five-year expansion plan (NERC Mini Grid Regulations, Sections 7b and 7c). Like other regulatory contracts, the contract specifies the terms and conditions of the developer's service. The template also specifies obligations for the community. For example, the community must provide land for the mini grid facilities with no or low leasing payments.

- **Private contract between a private developer, a community, and the distribution company that was given a license to supply electricity to the community.** NERC has developed a 19-page template for this tripartite contract (NERC 2017). The presumption is that it would be used in communities that are "poorly supplied" or in which there is "a nonfunctional distribution system." The expectation is that the mini grid will be connected to and use the distribution facilities of the licensed distribution company. The mini grid developer will pay a usage fee for its use of the distribution company's facilities (in other contexts, this fee is referred to as a leasing fee). In addition to this usage fee, the contract template includes placeholders for specifying tariffs for three other services: retail sales by the mini grid operator, mini grid purchases of electricity from the distribution company, and mini grid sales of electricity to the main grid.
- **Contract between a private developer, a local municipal government, and a grant-giving agency.** In the absence of a formal regulatory framework for mini grids in Haiti, the newly created electricity regulator is developing a template contract for an agreement between a private developer; the local municipal government within whose jurisdiction the mini grid will operate; and the Ministry for Public Works, Transportation, and Communications, which will provide financial support to the developer. The regulator will preapprove the template contract and provide an operating license to any developer that uses it. The regulator views the template contract as a way to catalyze the nascent mini grid sector while laying the groundwork for developing a more formal regulatory framework based on how the sector evolves over the next several years. Toward that end, the template contract strikes a balance between flexibility for the developer—allowing, for example, for different ownership-operating-maintenance models and letting the developer set its own tariffs, upon mutual agreement of the municipality and the ministry—and establishing regulatory guidelines such as minimum quality of service standards and a light-touch review of the tariff by the regulator, as required by Haitian law. The municipal government and the ministry have obligations as well: the municipal government must grant land rights, and the ministry must monitor the mini grid's performance. The template contract was developed with support from ESMAP, in consultation with mini grid developers, municipal governments, and the grant-giving ministry, through a series of workshops. It will be released for public comment in the second half of 2018.

Regulatory contracts are a relatively new phenomenon for mini grids. They have been used successfully in earlier cases of electricity privatization. In the late 1990s and early 2000s, regulation by contract was used to support the privatization or long-term concession of large electric distribution systems in Albania and Uganda. In both instances, the contracts were backed up by World Bank partial risk guarantee instruments to bolster compliance by the government and national regulators (Bakovic, Tenenbaum, and Woolf 2003). Under these guarantees, the new private distribution company would receive compensation from the World Bank if the national regulatory entity failed to implement the tariff-setting formula or other regulatory provisions included in the privatization or concession agreement. The guarantee was structured so that the government would reimburse the World Bank for any payments it made to the private investor. The counter-guarantee by the government was intended to provide an incentive for the regulator and government to live up to the terms of the agreement.

Regulatory contracts for mini grids are not magic bullets that will work in all circumstances. They are more likely to be successful if three conditions are met:

- The project's underlying economics makes commercial sense. To paraphrase one private mini grid developer, "If the numbers do not add up, the contract is just a lot of words on pieces of paper."
- The parties to the contract have economic incentives to live up to the terms of the contract.
- A timely and low-cost mechanism is in place that allows the parties to modify the contract if circumstances change.

ENDNOTES

[49]Even if there are clear, written mini grid rules and policies, investors may doubt that the rules will be implemented as written. This seems to be the case in Nigeria, where most of the planned privately owned mini grids will have installed capacities of less than 100 kW. Under Nigeria's rules, mini grids with an installed capacity less than 100 kW face very light regulation, suggesting that the developers' decision to build systems below this threshold may have been motivated by the desire to minimize regulatory review.

[50]An exception is OMC Power, the largest private mini grid developer in India, which has built mini grids in more than 75 villages in Uttar Pradesh. None of the them is connected to the grids of the local government-owned distribution companies, and there is no regulatory or policy clarity as what OMC's business options would be if these connections were to occur. Two factors may play a role in OMC's willingness to invest in Uttar Pradesh. First, OMC's assessment of the financial problems that distribution utilities in Uttar Pradesh face—and their subsequent inability to expand or provide quality service to many customers—may give it confidence that the market for its electricity will not disappear soon. Second, OMC received considerable assistance from the Rockefeller Foundation's Smart Power India program (Rockefeller Foundation 2018).

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