Role of Mini-grids for Electrification in Myanmar

SWOT analysis and a roadmap for scale-up

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1 Introduction

Myanmar's National Electrification Plan (NEP) aims to electrify 7.2 million households and achieve universal access to electricity by the year 2030. In the long run the extension of the Myanmar national electric grid will play a major role in meeting the 2030 target; by 2030, more than 95% of the population is expected to be connected to the national grid as a least-cost solution. In the medium term distributed electricity generation such as mini-grids and solar home systems (SHS) will play an important role in providing electricity to hundreds of thousands of households in areas that the grid will take many years to reach.[i]

Responsibility for implementing the off-grid component of the NEP is vested with the Department of Rural Development (DRD) under the Ministry of Agriculture, Livestock, and Irrigation. Within the off-grid component, case-by-case decisions will be made by the village residents, and project developers determining which households and villages will be served by community-scale mini-grids and which by household-scale SHS. The relative role of mini-grids vs. SHS depends on a number of factors including how fast mini-grid deployment can scale-up, the conditions under which mini-grids make sense compared to solar home systems, as well as the need to stretch limited resources (both time and money) for maximizing the level of quality services.

What is the appropriate role of mini-grids in achieving Myanmar's national electrification objectives? What steps can be taken to help increase cost-effective deployment of mini-grids in Myanmar? Following an overview of the current status of mini-grids in Myanmar, this note addresses the first question through a SWOT analysis of mini-grids vis-à-vis the objective of off-grid rural electrification. The second question is addressed in a "mini-grid roadmap" discussing key steps that government, developers, manufacturers, and financers should take to increase scale-up of mini-grids.

2 Current status of mini-grids in Myanmar

According to DRD data, out of 64, 000 villages in total, over 19,000 villages are considered by the DRD to have been electrified by off-grid means, through solar electricity, diesel generators, micro-hydropower, or biomass/biogas. Consistent with DRD data, the 2014 Myanmar census reports that 177,507 households used "private water mills" as primary source of lighting, while 1,013,149 households used generators (Table 1).[ii]

Table 1: Off-grid electrification by generation type and main source of lighting. Source of village-level data: Department of Rural Development and Ministry of Livestock, Fisheries and Rural Development, "Rural Electricity Access" (MoLFRD & World Bank Off-Grid Electrification in Myanmar, Naypyitaw, Myanmar, January 28, 2015). Source of household data: 2014 Myanmar Census.

Generation type (DRD data)	Number of villages	Main source of lighting (2014 Census data)	Number of households		
Category		**Category**	**Rural**	**Urban**	**Total**
Generator	13,088	Generator (private)	835,840	177,309	1,013,149
Mini-or micro-hydropower	2426	Water mill (private)	151,721	25,786	177,507
Biomass/gas	1232		N/A	N/A	N/A
Solar system	2693	Solar system/energy	902,431	42,811	945,242

Total	19,439		1,889,992	245,906	2,135,898
Total (not including solar)	16,746		987,561	203,095	1,190,656

The exact numbers of mini-grids are not known, but an estimate can be made by considering that most, if not all, villages electrified by diesel, mini-hydropower, and biomass/gas are served by mini-grids that aggregate the loads of multiple customers.[iii] The "solar system" category refers overwhelmingly to household scale solar home systems (SHS) and are generally not mini-grids (though there are a few – dozens but not hundreds – of solar mini-grids). Thus the sum total of villages in the table, subtracting "solar systems" is a reasonable estimate: somewhat more than 16,000.

The most common mini-grid generation technology observed in Myanmar is diesel generators. Generators are often small (under 10 kVA), using Chinese-made agricultural diesel motors powering inexpensive single-phase or three-phase synchronous generators.[iv] Tariffs for diesel mini-grids vary considerably, and are often charged per light or appliance. For example, in 2015 the ADB found 2000 kyat/month (USD 1.82/month)[v] typical for a single 20 watt CFL lightbulb, and 5000 kyat/month (USD 4.55/month) for two lights and a TV.[vi] Equivalent per kWh tariffs are between 800 and over 1100 kyat/kWh (USD 0.73 to over 1 USD/kWh).

Hydropower mini-grids appear to be concentrated in Shan, Mandalay, and Sagaing states.[vii] Tariffs are typically lower than those charged by diesel-powered mini-grids. Reference tariffs range from 200 to 860 kyat/kWh (USD 0.18 to 0.78/kWh).[viii] Biomass gasifiers are common in the delta region, powering mini-grids as well as rice mills, irrigation pumps, saw mills, oil pressing, and ice making.[ix] A reference tariff for biomass gasification mini-grids is 400 kyat/kWh (USD 0.36/kWh).[x]

Much less common at this point are solar mini-grids, either stand-alone or hybrid PV/diesel. Interviews with solar companies in Yangon as well as site visits and review of public documents suggest that there are dozens of solar mini-grids deployed so far, with dozens more in the pipeline.[xi] Most solar mini-grids have been heavily subsidized as pilot projects commissioned by NGOs or the DRD and have artificially low tariffs, if any.

Considering that the vast majority of Myanmar's mini-grids were built from scratch with no government support under conditions of acute materials shortages, Myanmar's mini-grid rural electrifiers have accomplished impressive feats. Some mini-grid distribution systems in Myanmar are built with high quality concrete poles and wires built to national grid standards. However, many are informal networks of wires strung on untreated wooden or bamboo poles or trees. Thin wires and poor splices have considerable line loss. They can also be dangerous and failure prone: poles rot and fall over, thin wires break easily, and poor splices corrode and fail.

The generators (diesel, micro-hydro, biomass) that energize Myanmar mini-grids are often inefficient, failure-prone, and unsafe. For example, manufacturers of micro-hydropower equipment often lack the tooling and designs to build high-efficiency, long-lived turbines. Micro-hydro mini-grids are generally built without electronic load controllers (ELCs) leading to wide variations in frequency and voltage. Many diesel generators use engines that are inefficient and have poor pollution performance. Synchronous generators attached to these prime movers often lack automatic voltage regulators (AVRs) and thus are unable to ensure steady voltages in the face of loads with changing power factor. Biomass gasifiers in Myanmar often have considerable air and water pollution problems. The one solar mini-grid visited by the author had challenges with battery and inverter failures.

More detailed research is needed on the costs, sizes, geographic locations, status, reliability, dominant failure modes, pathways for repair, and supply chains of mini-grids of various technologies. Findings from this future research should be incorporated into evolving NEP targets and strategies to meet these targets.

As the following SWOT analysis (section 3) shows, the deficiencies described above are not inherent in the technologies themselves, and there are significant cost-effective opportunities to improve quality and scale under the off-grid component of the NEP. Section 4 discusses specific tasks to achieve mini-grid scale up.

3 SWOT analysis

A SWOT analysis is an evaluation of strengths, weaknesses, opportunities and threats. The analysis groups key pieces of information into two main categories:

1. internal factors – the *strengths* and *weaknesses* internal to the technology and its characteristics
2. external factors – the *opportunities* and *threats* presented by the environment external to mini-grids (markets, regulation, competing technologies).

Table 2 below summarizes the SWOT of mini-grids in Myanmar.

Table 2: Myanmar mini-grid SWOT analysis summary.

	Positive (Favoring mini-grids)	**Negative (Not favoring mini-grids)**
Internal	**Strengths** • Internationally: technology can be robust if well-engineered • Favorable costs • Allows for productive uses • Enables local employment • Can grow with increasing demand • Hedge against volatile diesel prices • Can integrate with grid when it arrives • Foster collaboration and social cohesion at the community level through project planning, construction, operation and maintenance	**Weaknesses** • Shared resource challenges • Lack of sustainability in some projects point to persistent technical and governance weak points • Requires customization for each village • Lack of project pipelines
External	**Opportunities** • Renewable resources potentials • Prices dropping (especially PV) • Many existing diesel mini-grids in Myanmar • Experience with micro-hydro and biomass mini-grids by local firms • Private sector participation • Investment opportunities	**Threats** • Regulatory framework missing • Financing not available • Lack of collaterals or provision of credit guarantees

3.1 Strengths

3.1.1 Robust, yet maturing technology

Generation technologies used in mini-grids span a range of maturities from fully mature (e.g. diesel generation, mini-hydropower) to technologies that are still maturing (biomass gasification). There is good international experience constructing and operating mini-grids that reliably provide electricity – if well-built and well-maintained – for decades. Many of the component technologies (solar panels, inverters, diesel generators) are mature and manufactured/deployed at large scales. For example, solar panels mass-produced and used in grid-connected solar farms are perfectly suitable for mini-grids. Micro-hydro generators have been in use for over a century even if their deployment has not reached scales found with PV or diesel.

In addition to hardware, mini-grid technologies and practices regarding resource assessment, economics and business plan development, system/network design, operation and maintenance, and environmental and social sustainability have been developed, adapted, and tested in many contexts. Together with mini-grid hardware these constitute a complex socio-technical package. Success is certainly not guaranteed – developers need to pay attention to many variables. But examples of long-term success are not rare, especially if there is a strong market for the services the mini-grid provides.

Recent technology mini-grid improvements include radical price decreases in solar panels, new electricity storage options (lithium-ion batteries, flow batteries), improved controls, more efficient end-use equipment, and improved metering and billing technologies. Increases in the cycle life of batteries significantly improve the economics of solar mini-grids. An increasing variety of new billing solutions incorporate "pay as you go" (PAYG) metering using money transfers on cell phones or pre-paid cards. These technologies substantially reduce expenses with bill collection that has been a challenge with rural mini-grids. Remote monitoring using cell phone networks reduces O&M costs, repair costs, and down time by allowing problems to be diagnosed and repaired early by technicians before they result in failure.

3.1.2 Favorable costs for small communities far from grid

Mini-grids have favorable costs for remote communities with households that use relatively small amounts of electricity. The *Myanmar National Electrification Plan (NEP): Least-Cost Geospatial Electrification Planning Results*[xii] (henceforth referred to as *Geospatial Plan*) observes that "throughout the country, approximately 300,000 households, with a total population of perhaps 1.5 – 1.7 million (3-4% of the population) reside in communities which, due to sparse and remote settlement patterns, are estimated to cost more than USD 1,200 per household for grid connection." It is noteworthy that these cost estimates exclude per-household transmission and generation costs. If these households use 1000 kWh per year (as assumed in the base case of the *Geospatial Plan*) then the levelized cost of energy delivered to these households is at least 19 US cents per kWh.[xiii] If demand is only 250 kWh per year (an amount more than three times the design output of a "medium size" SHS under the NEP) then levelized cost of electricity from the grid is at least 38 US cents per kWh.

A World Bank-commissioned scoping study (Kumara, 2015) of six existing micro-hydropower projects in Myanmar found levelized cost of energy delivered to consumers to range from US 17 cents to US 67 cents per kWh (220 to 860 kyat/kWh).[xiv] Kumara estimated that LCOE could be reduced by 20% to 50%

by using improved technology which, while more expensive, performs significantly better increasing power output and reducing maintenance costs. However, it is possible that in some cases desired improvements to quality and reliability improvements may increase LCOE. In light of these uncertainties, it is worthwhile to consider costs of micro-hydropower plants built to desired standards outside Myanmar's borders. Nepal is a country with more challenging transport and access issues, similarly endowed with hydropower sites, but with a more developed micro-hydropower industry. As such, it serves as a conservative proxy for costs that could be expected after initial scale-up. A World Bank-commissioned study (Yamashita et al., 2015) of micro-hydropower mini-grids in Nepal built in 2012-3 found levelized costs averaged US 22.5 cents (for a 20 kW plant) to US 25.3 cents (for a 100 kW plant) per kWh.[xv] Per-household average costs of Nepali hydropower projects analyzed in this study ranged from USD 428 to 586 including distribution systems.[xvi]

Biomass gasification retail tariffs in Myanmar range from 40 to 60 cents per kWh.[xvii] Assuming an average tariff of 50 cents per kWh and a profit margin of 10%, levelized cost of delivered energy is estimated at 45 cents per kWh. A medium-size solar home system[xviii] under the NEP has an estimated initial capital cost of USD 380 and a levelized cost of energy of over 3 USD per kWh.

Levelized costs and initial capital costs of these rural electrification options are shown below in Figure 1. Biomass, diesel, and solar mini-grids have higher levelized cost of energy than grid extension unless consumption remains low (e.g. 400 Wh per day). As noted in the *Geospatial Plan*, even these are appropriate to build in rural areas since the generation assets are moveable and mini-grids can provide interim power while waiting for the grid to arrive. For mini-grids that provide small amounts of power per household in areas unlikely to receive electricity from the main grid, light-weight distribution systems with low-cost wiring are probably favorable. For mini-grids that provide grid-similar levels of electricity per household and projects in areas expected to receive the grid soon it probably makes more sense to build to distribution networks to the same standards that the main grid uses so that the investment in the mini-grid distribution system can be further used to distribute electricity when energized by the grid.

Micro-hydro powered mini-grids have favorable initial capital costs and favorable levelized energy costs in cases where consumption levels are relatively low (e.g. 700 Wh per day) even if grid-extension costs are low or moderate (e.g. well below average NEP phase 1 grid extension costs of US 700 per household[xix]) suggesting a substantial role for these mini-grids *instead of* grid extension, rather than *until* the grid arrives. More analysis is warranted to explore the conditions under which micro-hydro powered mini-grids are the favorable long-term solution especially in cases in which average consumption is closer to the 2470 Wh per day (1000 kWh/yr) assumed in the *Geospatial Plan*.

These findings extend, but are not contradictory with, the findings of the *Geospatial Plan* which modeled all mini-grids as diesel-powered. The document noted that "… the results of this modeling work should not be seen as precluding other system types, but rather as setting a cost maximum. If other, lower cost renewable or hybrid options exist, they will likely reduce the long-run cost of mini-grid systems, and can be implemented on a local basis."[xx]

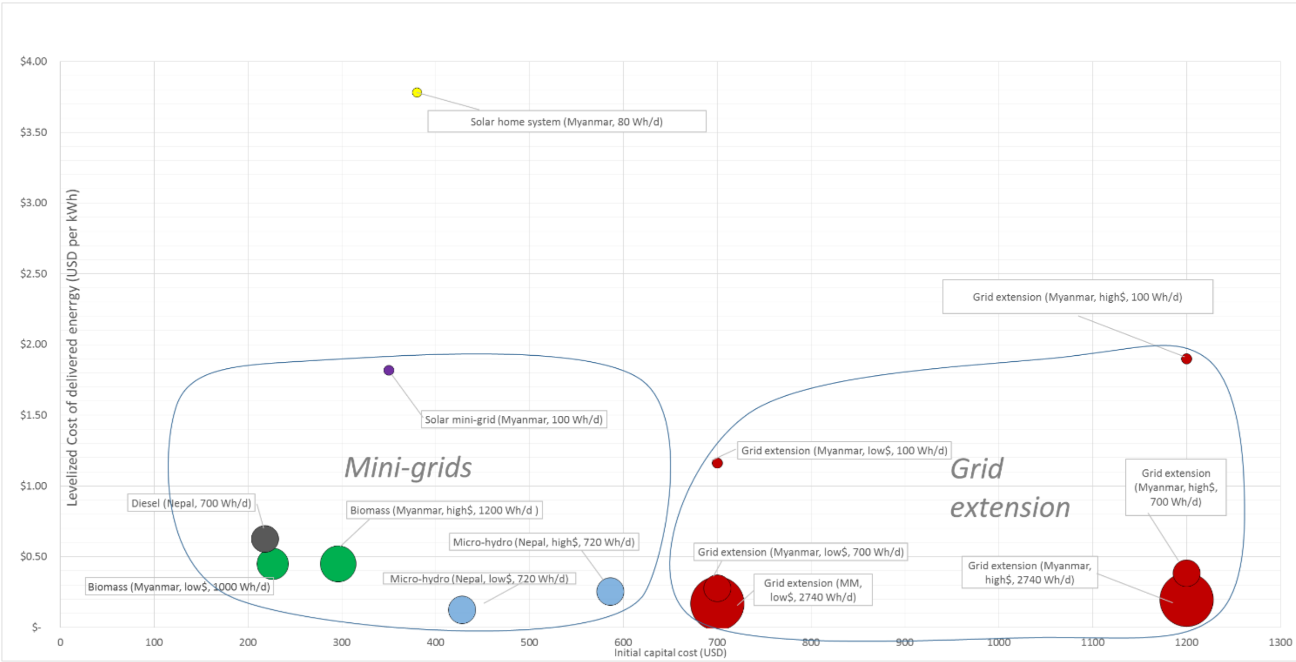

Figure 1: Indicative Initial capital cost per household (x-axis) vs. indicative levelized cost of delivered energy (y-axis) for Myanmar electrification options including SHS, mini-grids (hydro, diesel and solar), and grid extension. Mini-grid costs are based on published data for existing projects with signed contracts. Grid extension costs based from the Geospatial Masterplan. The area of each circle represents the amount of electricity per day. The left-hand circled grouping comprises micro-hydro, diesel, solar, and biomass mini-grids, whereas the right-hand circled grouping is grid extension costs. The point outside of the circles is a medium sized SHS. Labels indicate the country of origin of the data (Myanmar or Nepal), whether the cost estimate represents a low-cost end of the cost spectrum (low$) or high end (high$), and the assumed average daily household energy consumption. The spreadsheet used to generate this data, together with referenced sources, is available at: www.tiny.cc/mmminigridcosts.

3.1.3 Productive uses & local economy

Besides powering standard residential loads such as lighting, cell phone charging, and entertainment electronics (which SHS can also do), mini-grids can spur local economic growth through energizing larger productive use loads such as refrigeration, water pumping, saws, and agricultural processing such as rice mills or corn shelling. Keep in mind a couple of caveats. First: local economic growth requires much more than just availability of electricity. For example, access to transportation, nearby markets, and communication are necessary. Second, many of these needs can also be met with dedicated diesel motors or diesel generators used when needed. Dedicated stand-alone solar water pumping and solar-powered agro-industrial processing equipment are also available and affordable, displacing the need for mini-grids in some cases.[xxi]

Mini-grids provide direct employment for local populations, both during the construction phase as well as ongoing employment for one or more local powerhouse operators and electricity sales agents. Renewable energy mini-grids also help the local economy by insulating rural communities from price shocks when diesel fuel prices rise and providing new markets for agricultural residues (in the case of biomass).

3.1.4 Can grow with increasing demand and integrate with grid when it arrives

In many cases, mini-grid generation technology can start out small, and new equipment can be added as village loads grow. For example, a mini-grid may add solar panels, wind turbines, larger diesels, or (in some cases) additional batteries or micro-hydropower generators[xxii], expanding as the community's demand for electricity increases.

If built to sufficiently high standards, metering, household service drops, and the local distribution network used in a mini-grid can be connected to the main grid when it arrives. It is also technically possible for the mini-grid's generator (hydro turbine, solar panels, etc.) to connect and sell electricity back to the national utility. In both cases, regulatory rules will need to be developed to address the details of these transitions.

3.1.5 Foster collaboration and social cohesion at the community level through project planning, construction, operation and maintenance

Gaining access to electric services (and for this matter, infrastructure services in general) is a uniting force in many of the rural areas in Myanmar as the community recognizes its public benefits. It is common practice in Myanmar that Village Electrification Committee or Village Development Support Committee consisting of representatives of local residents, elders, and sometimes township officers/village administrators are formed and responsible for mobilizing financing and sourcing technical assistance support needed for grid extension projects. As discussed earlier, local communities are also responsible for hundreds of community mini-grid projects in place, including project planning, construction, operation and maintenance. Myanmar Peace Center has been promoting electrification as part of its peace-building mandate in conflict areas which are often off-limit to other programs or initiatives.

3.2 Weaknesses

3.2.1 Shared resource challenges

Renewable energy mini-grids, by their very nature, share a limited resource among a number of different users. In practice it can be difficult to prevent one household from using more than their share, impacting the ability of the system to provide electricity to others.[xxiii] In the case of mini-grids with lead acid batteries, collective overconsumption can harm the batteries.[xxiv]

For village mini-grids to be successful, each village needs to follow rules for sharing power, especially during times of shortages. Current-limiting devices and metering can help ensure that excessive consumption by a few does not deprive the rest of the community of electricity.

In addition, in the case of hydropower, use of water may need to be coordinated in space and time with agricultural uses. Biomass power plants use feedstock that many have competing uses as fertilizer, household cooking fuel, or industrial fuel.

3.2.2 Requires customization for each village

The customized attention required to develop mini-grids is likely to be the single largest bottleneck to mini-grid deployment in Myanmar.

Villages come in different sizes, require different amounts of electricity, and have different renewable energy resources. For these reasons, mini-grids (especially micro-hydropowered mini-grids) generally need to be customized for each village. This requires trained design engineers or technicians. Moreover, each mini-grid requires a local organization to operate and maintain the equipment, and collect tariffs. Minigrids' requirements for customization and local attention are particular challenges for the DRD, which is a new ministry with many responsibilities and tight timelines to meet NEP targets. Engineers with expertise in renewable energy are in high demand. In practice, the customized attention required to develop mini-grids is likely to be the single largest bottleneck to mini-grid deployment in Myanmar. SHS, by contrast, can be more easily deployed in large numbers, with identical kits installed in each house by technicians with basic training. The mini-grid roadmap works to address this through a process of capacity building and learning-by-doing to ramp up necessary skills.

3.3 Opportunities

3.3.1 Prices dropping (especially PV)

IRENA reported in September 2014 that prices for solar panels have dropped 80% since 2008[xxv], and the US Department of Energy expects prices to drop further in the coming years.[xxvi] As solar panels drop in price, solar powered mini-grids will be competitive in more villages compared to grid-extension and diesel generation. The prices of electronic balance of system (BOS) components such as controllers, inverters, and PAYG metering are also dropping. Mini-grid scale hydropower and biomass technologies do not benefit from the same degree of semi-conductor industry automation and economies of scale that solar enjoys, and are not dropping as quickly, but are benefitting from overall lower costs of electronic control systems and metering. Micro-hydropower costs vary considerably from site to site, and have strong dependence on the price of materials such as steel pipes and concrete as well as labor.

Lead acid battery storage costs have risen in step with increasing lead prices (four-fold increase in price of lead since 2003).[xxvii] Competing battery storage technologies such as lithium-ion and flow batteries have been falling in price. Compared to lead-acid batteries, advanced battery technologies have higher upfront cost and higher cycle life -- so that in certain mini-grid applications where low-cost finance is available they may be favorable. Thus far, lithium-ion and flow batteries have not been used in mini-grids in Myanmar.

3.3.2 Many existing mini-grids in Myanmar

Communities and local private companies in Myanmar have developed considerable experience with mini-grids. While some are old and operating at low levels of efficiency, many of these sites can be refurbished to use modern, efficient, reliable equipment for considerably less cost than building greenfield projects. With low-cost financing, most mini-grids powered only by a diesel generator can probably be profitably hybridized to include solar panels and/or battery storage, reducing the amount of diesel fuel consumed.

Much of Myanmar's experience in mini-grid deployment and operations has been gained the hard way – through trial and error. The experience of grassroots mini-grid practitioners provides a strong foundation upon which the NEP Off-grid component and other donor efforts can build, helping them adopt better (more cost-effective, efficient, more robust, safe) technologies and scale up deployment.

3.3.3 Technical assistance available

Development partners active in Myanmar, including Germany's GIZ, UK's DFID, Swedish SIDA, and the IFC have experience with renewable energy mini-grids. Countries in the region including Nepal, Sri Lanka, Indonesia, India, and the Philippines have considerable experience with renewable energy mini-grids. Development partners in these countries involved in mini-grids have begun sharing expertise with Myanmar in international forums in Myanmar and neighboring countries. [xxviii] At these forums and elsewhere, mini-grid experts have expressed interest in offering more extensive assistance to Myanmar.

3.4 Threats

3.4.1 Regulatory framework missing

A regulatory framework that addresses mini-grids is necessary to provide developers and investors the certainty that they need to build these projects, and to provide assurances to the public that mini-grids will provide reliable power at affordable prices. Components of the needed regulatory framework are described in section 4 below and include safety, quality of service, and tariffs. Until a utilities regulatory authority is established, components of this regulatory framework such as provisions allowing for interconnection of mini-grid distribution networks to the main grid and bulk purchase of electricity should be adopted by the DRD and the Ministry of Electricity and Energy (MOEE). Basic registration functions such as registration of micro-hydropower project sites to avoid competition of water resources can be accomplished through local DRD offices.

3.4.2 Uncertainty concerning grid expansion

Under the NEP, the national grid is expanding quickly in some areas, but others will not receive grid electricity for 15 years, if ever. Mini-grid developers will hesitate to invest if they suspect the national grid is arriving soon. To ensure that investment in mini-grids is made in the right places and not made in the wrong places, NEP maps must be updated to reflect the best, most recent estimates. These maps should be made available to stakeholders including mini-grid developers and village decision-makers.

3.4.3 Financing is not available or with very unattractive terms

Many mini-grid developers find it very difficult to get loans. Where they can get loans, they have short tenors (e.g. 1 year) and very high interest rates (40% or higher). With these terms it is nearly impossible to finance mini-grids that charge affordable tariffs. A consequence of high cost financing is that the private sector has built lower cost, less robust and less reliable mini-grids.

More generally, the financial sector is Myanmar is under-developed and local capital markets which provide securitized long-term capital for infrastructure is non-existent.

4 A roadmap for the mini-grid scale-up

The *Geospatial Plan* and the Project Advisory Document prescribe a significant role for mini-grids and other off-grid solutions in providing interim electrification until the main grid arrives, focusing on the more than 1 million households in villages which are unlikely to connect to the grid in the next 10 or more years.[xxix] Cost data reported in section 3.1.2 above further suggests an expanded role for micro-hydro mini-grids as a long-term electrification solution where sites are favorable.

The goal of a mini-grids roadmap is to scale up mini-grid deployment so that mini-grid investments are made where and when they make sense. Scale up of mini-grids requires simultaneous efforts by the government (especially the DRD, but also MOEE, Ministry of Education (formerly Ministry of Science and Technology (MOST)) and the Ministry of Industry (MOI)), manufacturers, developers, banks, and regulatory authority (when it is created).

Key requirements for a foundation upon which this growth can occur are: studies to better understand the mini-grid opportunities in Myanmar, the development of a regulatory framework that reduces risk to mini-grid developers while ensuring quality, reforms that improve access to finance, the adoption of planning practices that coordinate expansion of the main grid with mini-grid deployment and solar home systems, and capacity building for a variety of actors coupled with a robust process of learning-by-doing. DRD has a principal role to play in leading the off-grid program, managing the NEP budget, and ensuring that funds are well-spent creating a pipeline of efficient and cost-effective mini-grids. The MOEE has important roles to play in regulation (especially once the regulatory authority is created) and in implementing a planning process that coordinates grid expansion with off-grid investment and makes updated grid expansion plans available to mini-grid developers so that they can make informed judgements about where and whether to invest. The MOE has roles to play in capacity building, drawing on its existing renewable energy training roles and connections with Myanmar universities and vocational schools. The MOI is responsible for electrical safety and has responsibilities to develop safety codes for Myanmar mini-grids and provide for inspections.

Short-term, medium-term, and long-term goals for scale-up are shown below in Table 3. Detailed actions for the scale-up plan are discussed in Table 4.

Table 3: Mini-grid roadmap short-term, medium term, and long-term goals.

Timeframe	**Goals**
Short-term: stock-taking and pilot (1 year)	1. Determine status and location of (at least a representative portion of) present mini-grids. Determine broad understanding of challenges and technical improvement potential.

	2. Develop a model contract for use with pilot projects as a precursor to a regulatory framework. 3. Harmonize mini-grid deployment with grid-expansion and SHS plans with to maximize efficient use of resources. At a minimum this means making updated grid expansion plans available to mini-grid developers, as well as coordinating deployment of SHS and mini-grids to prevent duplication. 4. Initial capacity building for DRD, manufacturers, developers 5. Establish understanding between MOEE & DRD regarding connecting distribution system to main grid when it arrives. 6. Initiate 2-5 pilot mini-grid projects (combination of greenfield and refurbished) aiming to serve 500 households – installed by private sector, operating with viable business plans.
Medium-term: Pipeline building and enabling policy and regulations (3 years)	1. Triple mini-grid pipeline each year in years 2 and 3 so that the pipeline adds 5000 households in year 3. 2. Cost benchmarking study, standardization of components, economic benefit/cost study 3. Regulatory framework in place for mini-grids and grid-connected small power producers 4. Financial institutions provide favorable credit for mini-grids
Long-term: full scale-up (5 years)	1. Ramp up mini-grid pipeline meeting NEP target of approximately 15,000 households per year by year 5. 2. Ongoing capacity building as needed. 3. Program review and incorporate lessons.

Table 4: Mini-grid roadmap actions and timeframe

	Action	Detail	Timeframe
Pilots	Work with developers to pilot mini-grid projects under NEP procedures	Solicit project proposals or expressions of interest from developers. Provide transaction advisory services to help develop mini-grid proposals, connect developers with firms that can conduct pre-feasibility, feasibility and engineering studies as needed.	Pipeline of 2 to 5 projects (combination of greenfield and refurbished) with plan to serve over 500 households in first year, tripling every year thereafter.
Studies	*Studies are needed in order to fine-tune policy, planning and program design to better understand and respond effectively to the mini-grid situation in Myanmar*		
	Map existing mini-grids (hydro, biomass/biogas, solar, diesel) and create a database of their status.	Database should be GIS-compatible so that it can integrate with GIS datasets on population centers, existing and future grid expansion, hydrology and topography. Include fuel type, power ratings, network information, location, population served, energy use patterns, technologies used, investment and operations costs, experiences, current state of operations, electricity costs, nearness to the national grid based on expansion plans, etc., as well as renewable resource available.	80 projects within 1 year, with ongoing maintenance of database required.
	Identify cost-effective opportunities to refurbish or upgrade existing mini-grids to improve efficiency, reliability, and economic return.	Likely candidates for upgrades include: • mini-grid distribution networks, in many cases upgrading lines and poles so they are consistent with main-grid distribution standards • micro-hydro: turbines, generators, and control systems • biomass: control systems, waste management systems • diesel: solar hybridization	Start within first 6 months, ongoing.
	Create database of promising sites for new mini-grids	Criteria to include: local renewable energy resources, population distribution, loads, willingness to pay, and distance/planned arrival of the grid. Database should be GIS-referenced.	Start within first six months with 100 sites by end of year 1, ongoing.
	Determine economic costs and benefit of	Will help planners refine appropriate subsidy levels, determine or refine criteria	By end of 2nd year.

	mini-grids compared to other electrification options	for conditions under which villages merit mini-grid support, and better understand threshold conditions under which where mini-grids are likely to be preferable to the main grid.	
	Conduct cost benchmarking study and pursue standardization of components to reduce costs	• Conduct a thorough engineering based review of the manufacturing process and costing of mini-grids to establish cost benchmarks. • Benchmarking should be followed by standardization of components where possible as opposed to the high degree of customization that prevails today.	Benchmarking study within 1 year. Standardization steps within 3rd year.
Regulatory	*Regulatory framework for mini-grids should proceed in a pragmatic fashion starting with easier but important reforms and proceeding to more complicated arrangements as the regulatory apparatus is build that can address them.*		

	Regulatory framework "level 1"	• For hydropower mini-grids, initiate certificate/registration process by local government authorities to avoid conflict over sites and with other water uses.
		• Ensure that if a mini-grid distribution network is built to main grid standards, it can be used to distribute electricity from ESE when main grid arrives.
		    ○ This need not require existence of regulatory authority, but can proceed first as a policy memorandum between DRD and ESE with credible plans to sanction it as a rule under the yet-to-be formed regulator.
		    ○ An important precedent is already set with ESE allowing distribution franchisees (small power distributors) that purchase
			Within 1 year

		◦ bulk power and resell at a markup. ◦ Business models should be piloted that work through the details of the transition from mini-grid to small power distributor. Licensing and tariff regulation including: • Licensing or registration procedures for isolated mini-grids; • Rules for retail tariff setting including conditions under which tariffs are unregulated; • Rules that provide clear options for the mini-grid when the national grid extends into the mini-grid's service area; • Import tax deductions and income tax holidays for qualified renewable energy products. Quality control regulation (in coordination with the MOI and MOE) including: • Development of mini-grid safety and performance guidelines • Testing and certification process for manufacturers and developers.	
	Regulatory framework "level 2"	Address interconnection of mini-grid generators to sell electricity under feed-in tariff arrangements to ESE. • Standardized rules for interconnecting small distributed generation to the national grid; • Standardized feed-in tariffs for electricity sold back to the national grid; • A standardized power purchase agreement (PPA); and • A mechanism for assurance of the quality and reliability of electricity from mini-grids.	Within 2 years of formation of regulatory authority

<table>
<tr><td rowspan="3">Capacity Building</td><td colspan="3">Capacity building is necessary to bridge the gaps between the technology, practices, skillsets, and business models that have emerged in Myanmar during decades of isolation and best international mini-grid practice. Capacity building needs to be targeted and lean. Much of it should be conducted in ‘learning by doing’ opportunities shaped around developing a pipeline of mini-grid projects in Myanmar.</td></tr>
<tr><td>Capacity building for DRD</td><td>The DRD has responsibilities to facilitate and help fund mini-grid feasibility studies, evaluate mini-grid project plans, and ensure that capital subsides for mini-grids are well-spent. MOEE and DRD staff at all levels from union level to township level will benefit from improved understanding of mini-grids. Trainings are needed on:

• Best practices in site selection, mini-grid design and optimization, costing, and financial/economic analysis
• Project evaluation and program management
• Mini-grid business planning
• Technology; and
• Train-the-trainers training for mini-grid governance and tariff setting.

Manufacturers and developers will be engaged in detailed training on technology (described below) and government officials should facilitate and attend enough of these trainings to understand the nature of the challenges and the opportunities in various technology approaches and business models.</td><td>Start within three months and continue throughout five year NEP as necessary.</td></tr>
<tr><td>Capacity building for manufacturers and developers</td><td>Manufacturers and developers are faced with the task of rolling out high quality mini-grids, and providing ongoing support to operate these so they provide reliable, affordable electricity. Towards this end, capacity building is needed on:

• Technology: micro-hydro turbine design and manufacture, electronic load controllers, inverters, batteries
• Business management.</td><td>First training within 6 months. Trainings throughout 5-year NEP project as necessary.</td></tr>
</table>

		• Manufacturing processes, supply chains, and business models. • Mini-grid optimization, site assessment, equipment selection, how to conduct detailed engineering design, and installation. • Financial management to understand how to take advantage of new financial instruments and arrangements as they become available in Myanmar. Transaction advisory services for 2-5 pilot mini-grid projects in the first year, tripling every years.	
Capacity Building	Capacity building for village energy committees and private sector operators	Trainings on: • Mini-grid governance • Record keeping (financial, technical); • Tariff setting (such that revenues are adequate to cover operating costs including salaries, loan payments, and repair and maintenance). • Productive use technologies as battery charging, dryers, computer training centers, carpentry equipment, agro-processing. • Training on operations, maintenance, repair • Develop operator's manuals in Burmese (one for each hydropower, biomass, solar/diesel).	Trainings should occur early on in each mini-grid project's engagement with village. O&M trainings "learning by doing" during construction and after commissioning.
Finance	*In other developing countries, the World Bank or other development partners provide financing packages (credit lines, guarantees, etc.) that allow commercial banks to provide long tenor low-interest loans for mini-grids as well as trade financing to companies.*		
	Provide line of favorable credit to commercial banks to on-loan to mini-grids. If commercial banks cannot be brought onboard, consider alternative route with	Step 1: identify areas in which banks need to improve governance and performance in order to meet eligibility requirements Step 2: Work with banks to address shortcomings.	Determined by pace of banking reform. Target within 2 years.

	micro-credit institutions	Step 3: Ensure that eligible banks are provided opportunity to participate in mini-grid finance.	
	Capacity building for banks, investment firms, and/or micro-credit institutions	Trainings on mini-grid lending practices by Sri Lanka banks or other experienced financial institutions to evaluate the merits and risks of mini-grid projects and to gain experience with financial instruments suitable for mini-grid lending.	Determined by pace of banking reform. Target within 2 years.

Endnotes

[i] World Bank, “Myanmar - National Electrification Project” (Washington, D.C: World Bank Group, 2015), http://documents.worldbank.org/curated/en/2015/09/24977068/myanmar-national-electrification-projec.
[ii] A simple consistency check comprises dividing the “number of households” (census data) by “number of villages” (DRD data) in each category to calculate an average number of electrified households per village in villages with micro-hydro or diesel generators. The answer -- 73 to 77 households – is a reasonable number in Myanmar context.
[iii] While sometimes individual houses have their own diesel or even hydropower generator, typically whole villages are not electrified by every house having its own household-scale hydropower or diesel generation. Diesel generator statistics in this table are for “off grid” only and do not include the common practice of commercial and larger residential main grid-utility customers keeping diesel generators as a backup source.
[iv] Based on observations from author’s field visits to seven states/regions and discussions with Burmese who travel frequently to rural areas. See also, KWR, “Turning on the Lights: Integrated Energy and Rural Electrification Development in Myanmar: Comparative Cost and Technology Evaluation Relating to Rural Electrification,” 2014.
[v] This paper uses an exchange rate of 1100 kyat per USD, consistent with rates mid-year 2015. Source: http://www.xe.com/currencycharts/?from=USD&to=MMK&view=1Y
[vi] Pradeep Tharakan, “Off -Grid Renewable Energy Program in Myanmar,” accessed November 8, 2015, https://energypedia.info/images/b/bf/WB_NEP_seminar_ADB_presentation_Tharakan.pdf.
[vii] Personal communication, U Aung Myint, October 2015.
[viii] Ajith Kumara, “Off-Grid Hydropower Status of Myanmar” (The NEP Workshop on Off-Grid Electrification in Myanmar, Naypyitaw, Myanmar, January 28, 2015), https://energypedia.info/wiki/File:1-4_Myanmar_offgrid_2015-01_Ajith_Kumara_Hydropower_Status.pptx. Slide 30.
[ixix] One company alone, “Royal Htoo Linn Manufacturing Co., Ltd.” installed over 733 units as of August 2015. Of these, 358 were used to power rice mills and 145 for village electrification.
[x] Royal Htoo Linn Manufacturing Co.,Ltd., “Biomass Gasification as Renewable Energy” (Yangon, Myanmar, August 4, 2015).
[xi] Sunlabob, “Sunlabob Renewable Energy Secures Myanmar Contract for 11 Solar Grids,” *Eco-Business*, October 9, 2015, http://www.eco-business.com/press-releases/sunlabob-renewable-energy-secures-myanmar-contract-for-11-solar-grids/; ADB, “MYA: OFF-GRID RENEWABLE ENERGY DEMONSTRATION PROJECT Technical Assistance Concept Paper,” November 2013, http://www.adb.org/sites/default/files/project-document/79567/47128-001-cp.pdf.
[xii] Columbia Earth Institute, “Myanmar National Electrification Plan (NEP): Least-Cost Geospatial Electrification Planning Results” (Columbia University, Earth Institute, Sustainable Engineering Lab, August 2014).
[xiii] Assuming busbar costs of 13 cents per kWh, USD 1200 cost per connection, 10% discount rate, and 20 year evaluation period.
[xiv] Ajith Kumara, “Report of Off-Grid Hydropower Assessment of Myanmar” (World Bank, January 2015), https://energypedia.info/images/3/3e/REVIEW_REPORT_OF_OFF-GRID_HYDRO_POWER_Jan_23_2015.pdf.
[xv] Tomoyuki Yamashita et al., “Nepal - Scaling up Electricity Access through Mini and Micro Hydropower Applications : A Strategic Stock-Taking and Developing a Future Roadmap” (The World Bank, January 1, 2015), http://documents.worldbank.org/curated/en/2015/09/25091913/nepal-scaling-up-electricity-access-through-mini-micro-hydropower-applications-strategic-stock-taking-developing-future-roadmap-vol-2-summary. The study uses an exchange rate of 96 NRS per USD.
[xvi] Capital costs as reported in Yamashita et al. The calculated per-household connection cost figure also draws on Yamashita et al.’s finding that micro-hydropower projects average 8 households per kW.
[xvii] Personal communication with Patrick Pawletko January 2016, based on tariffs reported by Myanmar’s largest biomass gasification company Royal Htoo Linn Manufacturing Co. (RHL)
[xviii] 60 watt solar panel, 40 ampere-hour battery
[xix] Geospatial Masterplan, table 3, page 27.
[xx] Geospatial Masterplan, footnote 4, page 23.
[xxi] See, for example, the 2015 Powering Agriculture award winner “Solar Agro-Processing Power Stations” at https://poweringag.org/innovators/solar-agro-processing-power-stations

[xxii] Adding additional capacity to micro-hydropower is particularly difficult, requiring either an abundance of water and careful advance sizing civil of works sufficiently large to accommodate water flows necessary for an additional turbine; or a site that permits installation of a second micro-hydro downstream of the tailrace of the first power plant.

[xxiii] Chris Greacen, “The Marginalization of ‘Small Is Beautiful’: Micro-Hydroelectricity, Common Property, and the Politics of Rural Electricity Provision in Thailand” (Ph.D., University of California, Berkeley, 2004), http://palangthai.org/docs/GreacenDissertation.pdf.

[xxiv] Low voltage disconnect (LVD) circuits can help prevent overconsumption, but in practice these can be bypassed or reprogrammed.

[xxv] IRENA, “REthinking Energy” (International Renewable Energy Agency, September 2014), http://www.irena.org/rethinking/Rethinking_FullReport_web.pdf.

[xxvi] David Feldman, Galen Barbose, and Robert Margolis, “Photovoltaic System Pricing Trends Historical, Recent, and Near-Term Projections 2014 Edition” (NREL, September 22, 2014), http://www.nrel.gov/docs/fy14osti/62558.pdf.

[xxvii] http://www.infomine.com/ChartsAndData/ChartBuilder.aspx?z=f&gf=110567.USD.lb&dr=max&cd=1

[xxviii] See, for example, forums in Yangon, Bandung, and Colombo organized by the Hydro Power Network (HPNET): www.hpnet.org

[xxix] Columbia Earth Institute, “Myanmar National Electrification Plan (NEP): Least-Cost Geospatial Electrification Planning Results.”