DEVELOPING RENEWABLE ENERGY MINI-GRIDS IN MYANMAR

A Guidebook

ASIAN DEVELOPMENT BANK

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Abbreviations

AC	Alternating current
ADB	Asian Development Bank
DC	Direct current
DRD	Department of Rural Development
O&M	Operation and maintenance
PV	Photovoltaic
VEC	Village Electrification Committee

Measurement Units

GW	gigawatt-hour
kW	kilowatt
kWh	kilowatt-hour
l	liter
MW	megawatt
m^2	square meter
MWh	megawatt-hour
s	second
V	volt
W	watt
Wh	watt-hour

Currency Equivalent

Currency Unit	–	kyat (MK)
MK1.00	=	$0.00074
$1.00	=	1347.67MK

1

Introduction

This guidebook documents the experiences and lessons learned from the Off-Grid Renewable Energy Demonstration Project, an Asian Development Bank (ADB) technical assistance project in Myanmar, which was financed by the Japan Fund for Poverty Reduction. The project was completed with the Ministry of Agriculture, Livestock, and Irrigation (MOALI)[1] as the executing agency and the Department of Rural Development (DRD) within the ministry as the implementing agency.

ADB supported DRD, along with regional and local government agencies, to design and implement an off-grid renewable energy demonstration project that included three main components: (i) pilot mini-grids, (ii) a geospatial planning and off-grid investment plan, and (iii) a capacity-building program to strengthen the government's capacity in mini-grid development.

Pilot Projects

Under the project, solar mini-grid systems were successfully installed in 12 villages located in the country's Dry Zone (Magway, Mandalay, and Sagaing regions). These consist of 10 stand-alone projects, 1 diesel hybrid system, and 1 project built to grid standards so that it can be connected to the national grid when it arrives in the village (Table 1).

The ADB project funded 80% of the installation costs, while the villagers contributed the remaining 20%. After a tendering process, the Project awarded the contracts to install the systems to two local solar vendors (SolaRiseSys and Zaburitz Pearl). For each community, a Village Electrification Committee (VEC) was established. These VECs are responsible for payment collection from the villagers. The vendors have the responsibility to maintain the systems for 3 years. At the end of the first 3 years, the vendors will also replace the batteries with new ones, or provide the communities with a new set of batteries that can be installed at a later stage.

This guidebook documents the main experiences and lessons learned from the 12 pilot projects, as well as training materials from the capacity-building activities. It is intended to serve government officials, renewable energy developers, and potential investors in the development of mini-grid projects in Myanmar.

[1] Previously known as the Ministry of Livestock, Fisheries, and Rural Development.

Table 1: Pilot Projects with Renewable Energy Mini-Grids

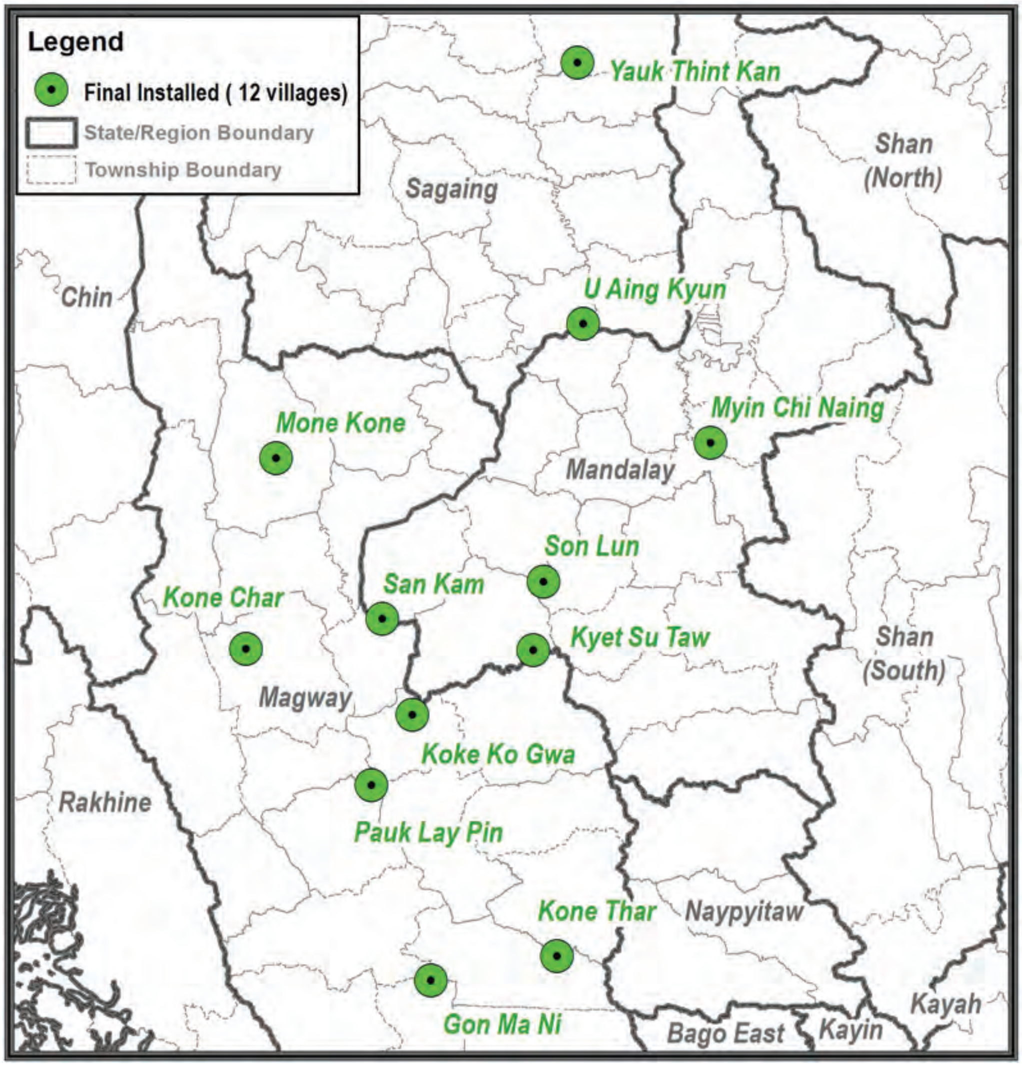
Township	Village	Number of Households	Population	PV Capacity (kW)	Battery Capacity (kWh)	Total Cost ($)	Type
Magway Region							
Thayet	Gon Ma Ni	197	931	7.2	57.6	73,350	Stand-alone
Sinbaungwe	Kone Thar	270	2,170	8.7	63.3	82,368	Stand-alone
Minbu	Pauk Lay Pin	89	336	4.9	57.6	44,100	Diesel hybrid
Yenangyaung	Koke Ko Gwa	330	1,654	13.0	92.2	102,300	Stand-alone
Salin	Kone Char	143	625	6.5	38.4	50,832	Stand-alone
Pauk	Mone Kone	157	836	6.0	46.1	50,856	Stand-alone
Mandalay Region							
Kyaukse	Myin Chi Naing	317	925	10.8	86.4	98,580	Grid ready
Nyaung-U	San Kan	200	977	9.8	115.2	75,000	Stand-alone
Kyaukpadaung	Kyet Su Taw	103	484	4.9	57.6	87,980	Stand-alone
Taungtha	Son Lun	110	654	4.9	57.6		Stand-alone
Sagaing Region							
Sagaing	U Aing Kyun	170	569	6.0	46.1	102,770	Stand-alone
Khin-U	Yauk Thit Kan	165	668	7.0	61.4		Stand-alone

kW = kilowatt, kWh = kilowatt-hour, PV = photovoltaic.
Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

The guidebook is structured as follows:

- Section 2 discusses major aspects of mini-grid development for rural electrification in Myanmar.
- Section 3 discusses the importance and approaches of community participation and gender mainstreaming in mini-grid projects.
- Section 4 summarizes the main lessons learned from the implementation of the 12 pilot projects.
- Section 5 discusses the main renewable energy technologies that are suitable for mini-grid development in Myanmar (solar, hydro, and biomass).

Figure 1: Locations of the Mini-Grid Pilot Projects



Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

2

Aspects of Mini-Grid Development

The following sections discuss major aspects of mini-grid development for rural electrification in Myanmar and incorporate the main experiences from the pilot projects.

2.1 Site Identification and Selection

Site selection should aim to identify unelectrified rural communities without prospects of being connected to the national grid in the next 5–10 years. These are typically located at least 10 kilometers from the national grid.

Under the National Electrification Plan, the Ministry of Electricity and Energy[2] has developed three subsequent phases of grid rollout, identifying villages that are recommended for grid connection in each phase. This should be a first-pass check on the suitability of a village for a mini-grid.

In addition, a village should also have sufficient demand for electricity and consist of a concentrated group of at least 150–200 households to make a mini-grid viable. Larger villages are preferable as these will be able to provide stronger revenue streams that will help sustain the mini-grid operation in the long run.

The existing sources of lighting and how much the villagers spend for lighting are also important considerations. If they depend on kerosene or candles, they might be more interested in renewable energy mini-grids. If they have a diesel-based mini-grid, the addition of a renewable component may lower the cost of generation. However, if several households in a village already have a solar home system installed (either from a Department of Rural Development [DRD] program or self-purchased), development of a mini-grid may not be feasible as these households may not be willing to contribute toward a mini-grid scheme.

For the pilot projects, selecting villages and maintaining their interest in participating in the project were major challenges. Discussions were held with more than 35 villages to find 12 suitable villages. Villages were not interested in participating for various reasons. For example, some are located relatively close to the national grid and were expecting to get connected soon. A number of villages were not willing or able to contribute their share of the project cost, or were not able to come to an agreement internally. One village decided not to participate even after signing the contract with the vendor. Therefore, programs or developers targeting multiple villages should identify a sufficiently large number of villages from an early stage so that replacement villages can be identified if needed.

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[2] Previously known as the Ministry of Energy and Power.

For the pilot projects, the following criteria were used to identify suitable villages:

- at least 2 miles (3.22 kilometers) from the national grid and low likelihood of grid connection in the next few years
- not part of DRD's national rural electrification program
- number of households higher than 200 and houses not scattered widely
- sufficient cohesiveness among the villagers to form a VEC and manage the project as a community
- ability and willingness of the villagers to contribute 20% of the projects costs and to pay for the electricity services
- ease of accessibility of the village, to bring in the equipment

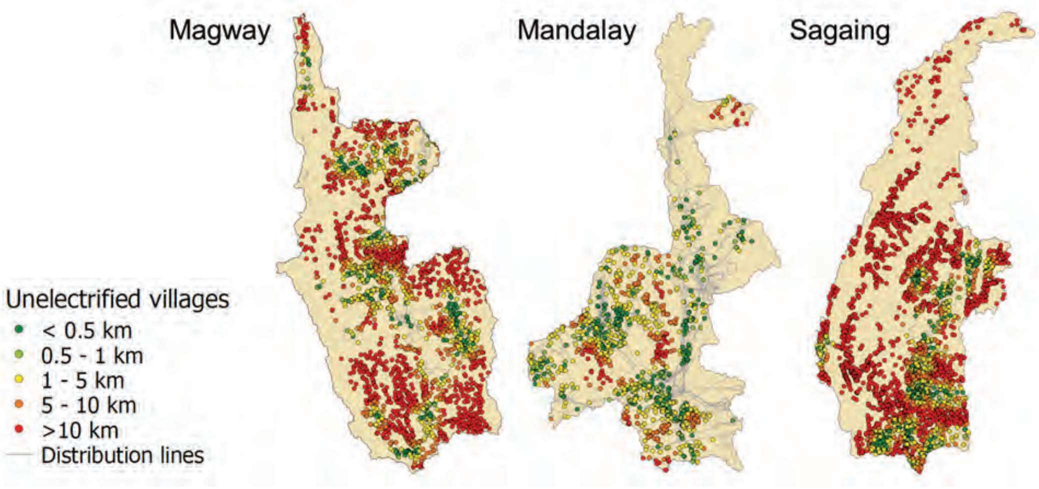
Table 2 and Figure 2 show the results of a geospatial analysis that classified villages by distance from the existing electricity grid in the Dry Zone (Magway, Mandalay, and Sagaing regions). This shows that particularly in Magway and Sagaing there is a large number of villages located at more than 10 kilometers from the grid, indicated as red dots.

Table 2: Unelectrified Villages in the Dry Zone

State/Region	No. of Villages	No. of Unelectrified Villages	Proportion of Unelectrified Villages (%)
Magway	4,294	2,380	55
Mandalay	4,834	1,418	29
Sagaing	5,694	3,762	66
Total Dry Zone	**14,822**	**7,560**	**51**

Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

Figure 2: Unelectrified Villages Classified by Distance from the Grid



Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

To support the identification of suitable sites for mini-grids, the project has developed a web-based geospatial mapping tool. The tool maps unelectrified villages in the Dry Zone and provides information on available local resources and nearby infrastructure for an estimation of the potential for off-grid investments. Users can select a variety of parameters, such as population, existing infrastructure, and natural resources, to interactively analyze the potential for off-grid electrification in Magway, Mandalay, and Sagaing regions (http://adb-myanmar.integration.org/).

2.2 Resource Assessment and Technology Selection

Several renewable energy technologies are suitable for mini-grids, as long as sufficient resources are available. These resources are typically site specific and may fluctuate seasonally. Therefore, it is crucial to conduct a proper resource assessment before choosing a particular technology. Preferably this should be carried out by experts with experience in assessing resources for a specific technology.

Renewable energy technologies suitable for mini-grids in Myanmar include solar, hydro, and biomass.[3] The most suitable technology will vary from project to project, but will foremost depend on sufficient resources available for electricity generation. Generally speaking, solar resource data can be obtained from indirect sources such as satellite data and nearby weather stations, while hydro and biomass require on-site measurements and investigation to assess available resources.

Regardless of the resource, all types are subject to seasonal variations that need to be carefully considered. Under the right circumstances, hydro and biomass can provide higher loads and longer hours of service compared to solar mini-grids. However, they also require more elaborate resource assessments and feasibility studies, which can be a lengthy and costly process. This may limit the ability of communities to implement such projects.

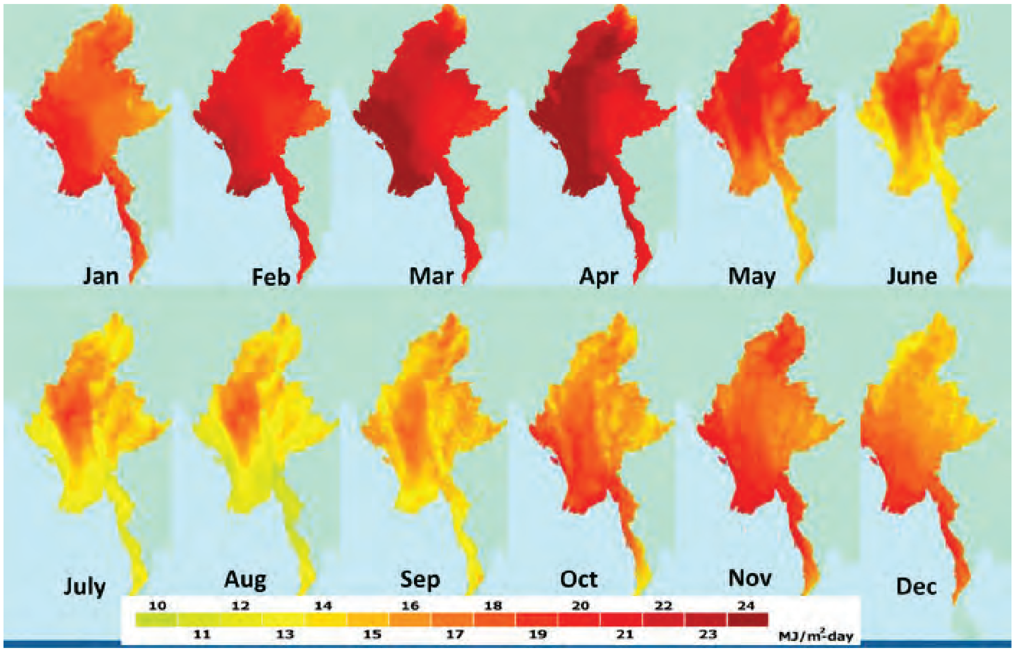
Solar

Myanmar has an average solar irradiance of 4.5–5.1 kilowatt-hours per square meter per day (kWh/m^2/day), making solar a suitable technology for mini-grids in many locations. Nevertheless, strong variations exist in the different areas of the country. Solar irradiance at a particular site can be obtained from on-site measurements, or derived from satellite data and nearby weather stations.

Figure 3 shows the solar irradiance in Myanmar from month to month. This clearly shows a strong variation between the dry and rainy seasons in many places. The Dry Zone (consisting of Magway, Mandalay, and Sagaing regions) is highly suitable with an average radiation of more than 5 kWh/m^2/day and limited variation in radiation during the rainy season. Outside the Dry Zone, irradiance can go down by as much as 50% in the rainy season, meaning that more batteries would be needed to be able to provide continuous electricity service. Therefore, areas with heavy and prolonged rainy seasons may be less suitable for solar.

[3] Section 4 of this guidebook has more details on each technology.

Figure 3: Monthly Solar Irradiance in Myanmar



m² = square meter, MJ = megajoule.
Source: Myanmar Green Energy Summit 2015.

Hydro

Myanmar has many areas with rivers and streams. This makes hydro a suitable choice for those areas. Hydro is dependent on a river or stream with a sufficient water flow and drop in height to be able to continuously generate electricity. It is one of the oldest and most established forms of renewable energy, and a good site can provide electricity for large communities at relatively low investment costs per unit of generation. However, the site needs to be sufficiently close to the community. Otherwise, the costs of connection may be too high.

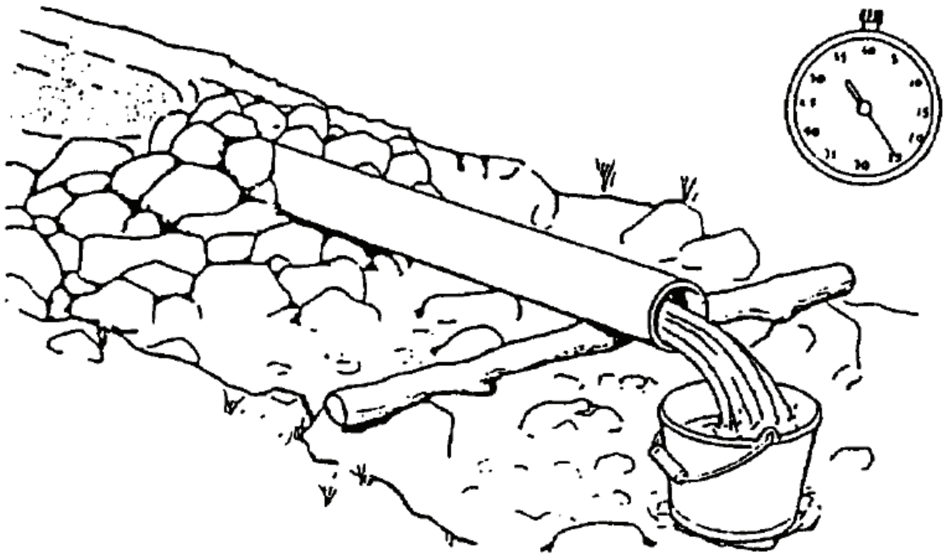
A resource assessment should be conducted on-site and include a study of the geological features of the site. Measurements of the water flow should be conducted over a longer period and cover the dry season to establish the minimum potential generation capacity. Figure 4 illustrates an example of flow measurement.

Figure 5 shows (a) the river network and (b) watersheds in the Dry Zone. The map on the right shows townships that have potential for hydro development.

Biomass

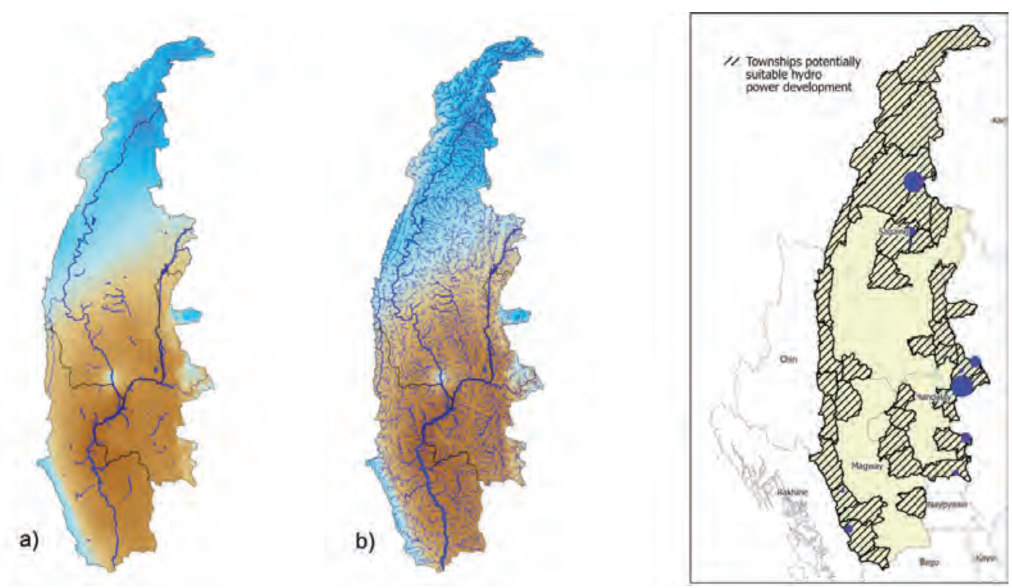
Biomass projects make use of organic materials such as wood, rice husk, bagasse, corn cobs, or coconut shells, which can be used to generate heat, steam, and/or electricity. Biomass is suitable for mini-grids at a site with a sufficiently constant supply of biomass feedstock at a central location—for example, rice husk from a nearby rice mill. Residues from harvesting are

Figure 4: Example of Flow Measurement



Source: Government of the Philippines, Department of Energy (2009).

Figure 5: Hydropower Potential in the Dry Zone



Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

Rice husk at a rice mill
Photo credit: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

typically less suitable because they need to be collected from a widespread area, which may be too costly and time-consuming.

Contrary to solar and micro-hydro, biomass can be stored for a long time and used when energy is needed. Nevertheless, biomass resources may also fluctuate from season to season, depending on harvesting and milling cycles, so shortages may occur. The resource assessment should also take into account that not all residues generated may be available for energy, because they could already be used for other purposes such as cattle feed or fertilizer.

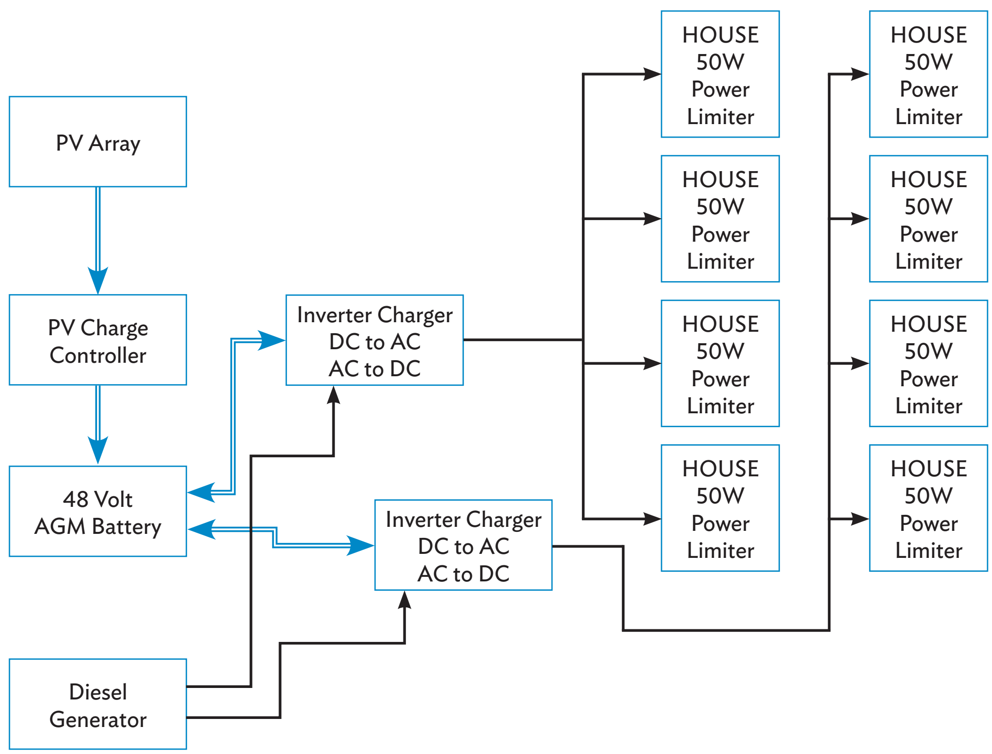
The long-term availability of biomass over the lifetime of a project is also crucial. While initially biomass may be available in abundance and at low cost, this may change over time, so the assessment should consider potential future uses for other purposes—for example, for other biomass energy projects or non-energy purposes.

Hybrid Systems

In certain cases, it may be worthwhile to explore the suitability of a hybrid system, which combines a renewable energy technology with a diesel generator. This provides backup to the renewable component and can ensure a continuous supply of electricity in case the renewable resource is insufficient to meet the demand (e.g., hydro in the dry season or solar in the rainy season). A hybrid system may also allow for a smaller battery pack, which is one of the most expensive components and most prone to failure.

Hybrid power systems typically rely on renewable energy to generate 75%–99% of required output (Alliance for Rural Electrification 2014). Some systems may only use the diesel generator occasionally because the renewable system can supply the required load. Especially for communities that already rely on a diesel-based system, it may be feasible to add a renewable technology to complement the existing system. This can lower the average cost of electricity, while retaining the existing infrastructure and providing a backup solution. The layout for a hybrid mini-grid system is illustrated in Figure 6.

Figure 6: Layout for a Hybrid Mini-Grid System



AC = alternating current, AGM = absorbent glass mat, DC = direct current, PV = photovoltaic, W = watt.
Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

For the pilot projects, it was the intention to implement one project as a hybrid project, by connecting with an existing diesel generator. One village with a diesel system in place withdrew its support after initial interest. In a second village the existing generator was found to produce low quality alternating current (AC) power with high-voltage fluctuations. Since this could damage the inverters and charge controllers, it was decided to create a switch arrangement that allows the diesel generator to supply power if the batteries become too deeply discharged to use the photovoltaic (PV) system. Effectively this means there are two parallel generation systems in place rather than a true hybrid system that would allow the generator to charge the batteries.

2.3 Energy Demand Assessment

An energy demand assessment is a crucial step in mini-grid development and serves two main purposes:

(i) Establish current energy-use patterns and corresponding expenditures, such as candles, kerosene lamps, and charged batteries. This helps to establish how much households would be willing or able to pay for electricity. Ideally, a mini-grid project should aim to provide an improved service at a cost lower than what households currently spend.

(ii) Estimate expected levels of electricity demand after the system installation. This helps to assess the capacity requirements of the system and the level of service that can be offered. This may range from basic lighting for a few hours per day to around-the-clock service allowing for higher loads.

The demand assessment should consider all types of potential customers and their energy needs, including

- households: lighting, mobile phone charging, TVs, and possibly larger appliances such as fans and refrigerators;
- commercial loads: lighting and appliances for eateries, entertainment venues, and small shops;
- community centers: lighting, computers, and other appliances for schools, temples, etc.;
- productive loads: processing of agricultural products, manufacturing, etc.; and
- streetlights.

A careful assessment of each of these categories is required to make sure that the system can handle the projected demand for electricity. It may also help to decide which technology is most suitable for the service required. The demand assessment should be conducted with close involvement of the community in order to fully understand their current energy-use patterns, their ability to pay, and expected electricity demand.

It should be noted that service levels may vary widely and can be classified in tiers, as shown in Figure 7. These range from Tier 0 (no electricity) to Tier 5 (high-quality service allowing for full loads with minimal interruptions). To minimize the up-front investment costs, a mini-grid for communities without previous access to electricity may start at Tier 1 or Tier 2 and could gradually evolve to higher tiers, depending on available renewable resources and future demand.

For each type of consumer, the demand assessment should estimate a profile of expected electricity use throughout the day. Table 3 shows an example of a load profile for an average household. It accounts for the number of appliances and the duration that each appliance will be used. The first table shows inputs that should be obtained from interviews and surveys. The second table shows the resulting demand profile. In this example, total average electricity demand per household is 250 watt-hour (Wh) per day.

Figure 8 shows a graphic representation of the daily load profile for an average household, with a peak in the evenings between 8 p.m. and 11 p.m. This will affect the system configuration.

Figure 7: Energy Access Multi-Tier Framework

hr = hour.
Source: Sustainable Energy for All (SE4All).

Table 3: Estimation of Average Household Demand

Electricity demand (Wh)

Appliance	Watts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LED lights	5	1	1	1	1	1	1												3	3	3	3	3	3	1
TV	30																					1	1	1	
Phone charger	5						1	1	1				1							1	1	1			

Electricity demand (Wh)

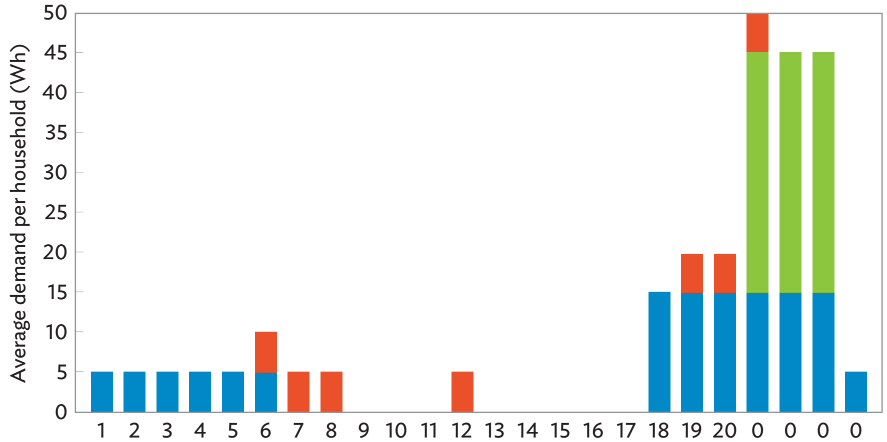
Appliance	Total	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LED lights	125	5	5	5	5	5	5												15	15	15	15	15	15	5
TV	90																					30	30	30	
Phone charger	35						5	5	5				5							5	5	5			
Total	**250**	**5**	**5**	**5**	**5**	**5**	**10**	**5**	**5**				**5**						**15**	**20**	**20**	**50**	**45**	**45**	**5**

LED = light-emitting diode, Wh = watt-hour.
Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

For example, a solar mini-grid will need to have sufficient battery capacity to be able to supply electricity in the evenings.

In a similar manner, load profiles for other customer types should be developed to assess the overall demand that the system will need to meet. This will be the basis for the technical design of the system.

Figure 8: Example of an Average Household Daily Load Profile



Wh = watt-hour.
Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

As households and other customers become familiar with the electricity services, they can be expected to request more service-hours and have the ability to use larger appliances. Therefore, demand estimates should also take into account that demand may increase over time.

2.4 Business Planning

Once there is sufficient basic clarity about the potential for a mini-grid, business planning is helpful to tie together the different elements. Among other aspects, business planning covers the following elements:

- ownership structure,
- fees and payment collection, and
- financial analysis.

Ownership Structure

For mini-grids, the following ownership models are the most relevant:

- **Community ownership and management**. In this model, the community becomes the owner and operator of the system and provides maintenance, tariff collection, and management services. Typically, this model requires grant funding to cover the investment costs, possibly supplemented by a contribution from the community in cash or in kind. It also requires a long development period, as well as technical and social capacity building to build the skills needed and to avoid potential conflicts. This may require an outside party to facilitate and support this process. After installation, the system would be transferred to a community organization. This could be a cooperative, with the electricity customers as members. Project operations are typically managed by a village committee consisting of representatives from the members. This committee oversees operations and makes decisions about electricity charges, fee collection, system maintenance issues, and any expansion of the system. Community-based mini-grid management may be the only option in remote and small communities that do not attract private sector or utility interest.

- **Private ownership and management**. In this case, an individual or a company invests in, builds, and operates the mini-grid. This could be a member of the community, a utility company, or an energy service company that invests in multiple projects. Community members may be employed for operation and maintenance (O&M). Typically, this model is feasible only for larger communities with several commercial and productive customers besides households so that the initial investment can be recovered in a relatively short time (3–5 years). Ideally, it also requires regulations that provide concessions and provisions for when the grid arrives in the village. However, at this point, such regulations are not in place in Myanmar, meaning that there is a relatively high risk to this model.
- **Community and/or private ownership**. In some cases, a combination of the previous ownership models may be suitable. For example, a private entity may invest in the generation and the storage component, whereas the community invests and owns the distribution infrastructure, and manages payment collection. This could lower the overall investment costs and make the project more attractive to a private entity. Nevertheless, such an arrangement requires clearly defined agreements that specify the roles and responsibilities of each entity for O&M to avoid conflicts and failures.

The most suitable business model for a particular community will depend on a variety of factors, such as size of the community, level of village cohesion and management capability, private sector interest, and the availability and need for grant funding.

Fees and Payment Collection

Besides ownership, mechanisms for setting user fees and collecting payments need to be established and agreed upon. This is one of the most crucial factors in ensuring the ability to keep the project operating over a long period. At a minimum, the fees need to cover the O&M of the system, including periodic replacement of major components such as batteries. For privately owned projects, the fees should allow for a reasonable profit to make the initial investment worthwhile. At the same time, the fees need to be within the consumer's ability and willingness to pay. Keeping the fees sufficiently low to stimulate the use of electricity for commercial and productive uses could also allow for a more evenly balanced daily load profile and stronger revenues once the system becomes operational.

Fees may be set separately both for the connection and the use of electricity. Connection fees may be set to cover the cost of meters and other equipment as well as to obtain a solid commitment from users. Fees for the use of electricity can apply two different structures:

- **Fixed weekly or monthly fee**. This could be based on a limited amount of electricity or a number of appliances used such as lights. For the pilot projects, this mechanism was used for households, with a fixed fee of MK1,500 ($1.11) per month and supply capped at 100 watt-hours (Wh) per day. This covers a basic load of two indoor lamps for up to 6 hours per day plus mobile phone charging. The monthly fee is equivalent to about MK500/kWh. The vendors also have the option to provide additional electricity beyond the basic service, for which users would pay higher tariffs.

- **A tariff per kilowatt-hour**. Users pay according to use, measured periodically (e.g., at the end of the month). This requires meters to be installed at the site of consumption. Meters can use a prepaid system, under which the user buys credits for a certain amount electricity in advance, known as pay-as-you-go (PAYG). After the electricity has been used up, the electricity supply is shut off and the user needs to buy new credits. Prepayment meters are commonly used for off-grid electricity systems as they simplify the tracking of consumption and payment collection. However, they are much more expensive than regular meters.

A combination of the structures can be used as well. For example, households pay a fixed fee and larger consumers pay according to use. Regardless of the mechanisms used, payment structures need to be clearly defined and agreed upon with communities, and be communicated clearly to all users.

Financial Analysis

Financial analysis is performed to assess the financial feasibility of a project. This is important for privately owned and operated projects, as an investor wants to know up front whether the investment can be profitable within a reasonable time period. However, this is also important for (largely) grant-funded projects, because payments for connections and electricity services need to be sufficient to sustain the O&M of the system. Therefore, financial analysis is needed to determine the minimum fees that are required for this.

Financial analysis considers a variety of financial factors. Table 4 shows an example of the inputs for a basic financial model, based on some of the financial parameters of the pilot projects. This includes the following elements:

- **Project costs**. These include all the equipment, as well as the cost of labor and transport to install the system.
- **Financial contributions**. These include grants, contributions from the community, and private investment.
- **Service fees**. These are the fees that users pay for using electricity, either as a fixed fee or per kilowatt-hour.
- **Connection fees**. These are the fees that customers may need to pay to get connected and receive service.
- **Operation and maintenance**. These include the salaries of technical and administrative staff, running costs, spare parts, and periodic replacement of major components like batteries.

In this example, tariffs are segregated in two levels: MK500/kWh for the first 100 Wh on any given day, and MK1,500/kWh for additional use. It is also assumed that a developer or investor will provide 20% of the initial capital costs and replace the batteries after 5 years of operation.

Table 5 shows the results of the financial model based on these assumptions. This shows the project can provide an attractive return under these assumptions.

Table 4: Input Parameters for Financial Analysis

Daily Loads and System Design

Basic Load Estimation	W	per HH	Hours/Day	Wh/HH/Day
5W LED	5	3	6	90
9W LED	9	0	5	–
5V 5W USB charger	5	1	2	10
		Basic load per HH (Wh/day)		**100**

Household Demand		No.	Wh/HH/Day	Wh/Day
No. of households		200		
Basic consumers	50%	100	100	10,000
Medium consumers	30%	60	200	12,000
High consumers	20%	40	400	16,000

Additional Loads	Hrs/Day	No.	Wh/Unit/Day	Wh/Day
10 W streetlights	6	20	60	12,000
Commercial users		5	500	2,500
Total design Load—Daily energy needed (Wh)				**52,500**

Tariffs and Expenses

Electricity Tariff		
Households—Basic	500	MK/kWh
Households—Extra	1,500	MK/kWh
Enterprises	1,500	MK/kWh
Annual tariff increase	0%	per year

Operating Expenses		
General (1% of capex)		$1,500

Battery Replacement		
Battery costs (25% of capex)		$37,500
Battery replaced every (years)		5

Miscellaneous		
Inflation		
Exchange rate	1,330	MK/US$

Investment and Expenses

System Design	
Overall conversion efficiency	70%
Daily charging required (Wh)	75,000
Peak sun hours	4.5
Suggested PV array (Wp)	16,667
Days of autonomy (@ 50% max DOD)	2
Battery capacity (AH @ 24V)	12,500

System costs	
System installed cost - $ per Watt	$9.00
Total system installed cost	**$150,000**

Sources of Funding	
Community (%)	20%
Grant funds (%)	60%
Developer's investment	$30,000

AH = ampere hour, Capex = capital expenditure, HH = household, DOD = depth of discharge, Hrs = hours, kWh = kilowatt-hour, LED = light-emitting diode, MK = kyat, No. = number, PV = photovoltaic, W = watt, Wh = watt-hour, Wp = peak watt, V = volt.

Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

Table 5: Example of Mini-Grid Financial Model

Year	1	2	3	4	5	6	7	8	9	10
Electricity Consumption (kWh)										
Households—Basic	7,300	7,300	7,300	7,300	7,300	7,300	7,300	7,300	7,300	7,300
Households—Extra	6,570	6,570	6,570	6,570	6,570	6,570	6,570	6,570	6,570	6,570
Commercial users	913	913	913	913	913	913	913	913	913	913
Streetlights	4,380	4,380	4,380	4,380	4,380	4,380	4,380	4,380	4,380	4,380
Total	**19,163**	**19,163**	**19,163**	**19,163**	**19,163**	**19,163**	**19,163**	**19,163**	**19,163**	**19,163**
Revenue ($)										
Households—Basic	2,744	2,744	2,744	2,744	2,744	2,744	2,744	2,744	2,744	2,744
Households—Extra	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410	7,410
Enterprises	1,029	1,029	1,029	1,029	1,029	1,029	1,029	1,029	1,029	1,029
Connection Fees	–	–	–	–	–	–	–	–	–	–
Total Revenue	**11,183**	**11,183**	**11,183**	**11,183**	**11,183**	**11,183**	**11,183**	**11,183**	**11,183**	**11,183**
Operating Expenses	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Net Profit	9,683	9,683	9,683	9,683	9,683	9,683	9,683	9,683	9,683	9,683
Battery replacement		FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
Investment	(30,000)	–	–	–	–	(37,500)	–	–	–	–
Cash flow	(20,317)	9,683	9,683	9,683	9,683	(27,817)	9,683	9,683	9,683	$9,683
Cumulative cash flow	(20,317)	(10,633)	(950)	8,733	18,416	(9,400)	283	9,966	19,649	29,333
IRR	27%									
Payback period	5.9 years									

( ) = negative, IRR = internal rate of return, kWh = kilowatt-hour.
FALSE = Battery will not be replaced in the modelled year.
Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

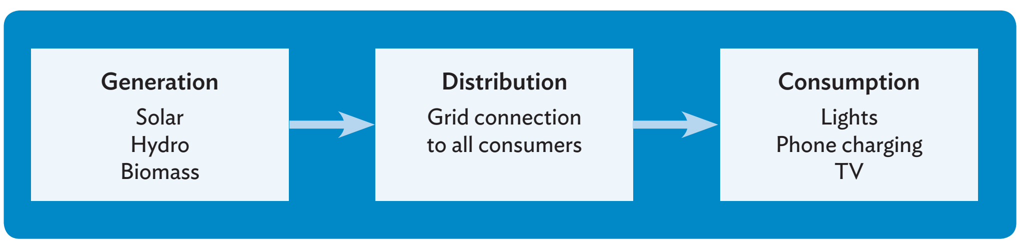
2.5 System Design, Installation, and Commissioning

A renewable mini-grid consists of three main subsystems:

(i) **Generation**. This comprises the power sources (solar panels, turbines, or engines), batteries, charge controllers, and inverters. These determine the amount of electricity that can be produced by the system.
(ii) **Distribution**. This involves the method of delivering the electricity to the end users through a grid covering the community. Different choices can be made for the grid: DC or AC; single- or three-phase; and basic or grid-ready, meaning that it can be connected to the main grid when it arrives in the community.
(iii) **Consumption**. This includes all the equipment at the site of consumption, including meters, power limiters, electric sockets, and appliances such as lights, fans, and TVs.

Mini-grids for rural electrification are often stand-alone and typically face budget constraints, so the design of the subsystems should be conducted in an integrated manner, as each subsystem is closely related and should be compatible with the others (Figure 9). Apart from the project costs, system design also determines the cost of energy generation and the quality of services delivered to the end users.

Figure 9: Mini-Grid Design and Operation as Whole Systems



Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

Several tools are available to support the design of a mini-grid:

- **GIZ Mini-Grid Builder**. This is a free web tool aiming to reduce up-front project development costs through the utilization of site survey data. Users can perform calculations on the energy demand and the required generation capacity. The tool includes financial analysis that facilitates the projection of an initial project budget (http://www.minigridbuilder.com).
- **HOMER**. This is a software for micro-grid and distributed generation power system design and optimization (http://www.homerenergy.com).
- **RETScreen**. This is a Clean Energy Management Software system for energy efficiency, renewable energy, cogeneration project feasibility analysis, and ongoing energy performance analysis (http://www.nrcan.gc.ca/energy/software-tools/7465).

Mounting rack for photovoltaic panels during mini-grid installation
Photo credit: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

Determining the right capacity of the generation system can be a challenge for a community mini-grid, especially for communities without previous access to electricity services. If the system is oversized, project costs will be too high, leading to high tariffs, and some of the capacity will not be used. If undersized, some components may be overstressed, leading to higher maintenance costs and possibly system failure. At the same time, the system will not be able to meet demand from the end users and lead to dissatisfied customers. The possibility of a modular design may be considered to avoid this.

In designing the system, several considerations are important:

- **Alternating current or direct current**. This depends both on the technology used and the end use of the electricity. PV and batteries produce direct current (DC) power, while hydro and biomass normally produce alternating current (AC) power. Highly efficient DC lights and other small household appliances are available, but commercial or productive applications may require AC power.
- **Single- or three-phase distribution grid**. A single-phase grid is cheaper but can only handle small appliances. The use of larger equipment requires a three-phase grid. This would also allow for the distribution grid to connect with the national grid when it arrives.
- **Batteries**. If the system includes batteries, these need to be deep cycle. The capacity of the battery pack will be determined largely by the number of days that the system should be able to supply electricity without recharging and without draining the batteries. This depends on the expected number of consecutive days without sufficient sunshine during the rainy season.
- **Wires and conduits**. These need to be sized for minimal voltage drop (line loss). They also need to be secured firmly and protected from physical damage, ultraviolet, and weather.

- **Circuit protection**. This is required in the form of fuses and circuit breakers. It is essential that all wires connected to batteries have circuit protection.
- **Flood protection**. As many areas in Myanmar are prone to severe flooding, the system should be installed at elevated heights or locations with minimal exposure to flooding. This will allow the system to continue operations, or at least avoid major damage, during occurrences of flooding.

Table 6 outlines the components of a solar mini-grid servicing 200 households.

Figure 10 shows a corresponding example of the corresponding system layout.

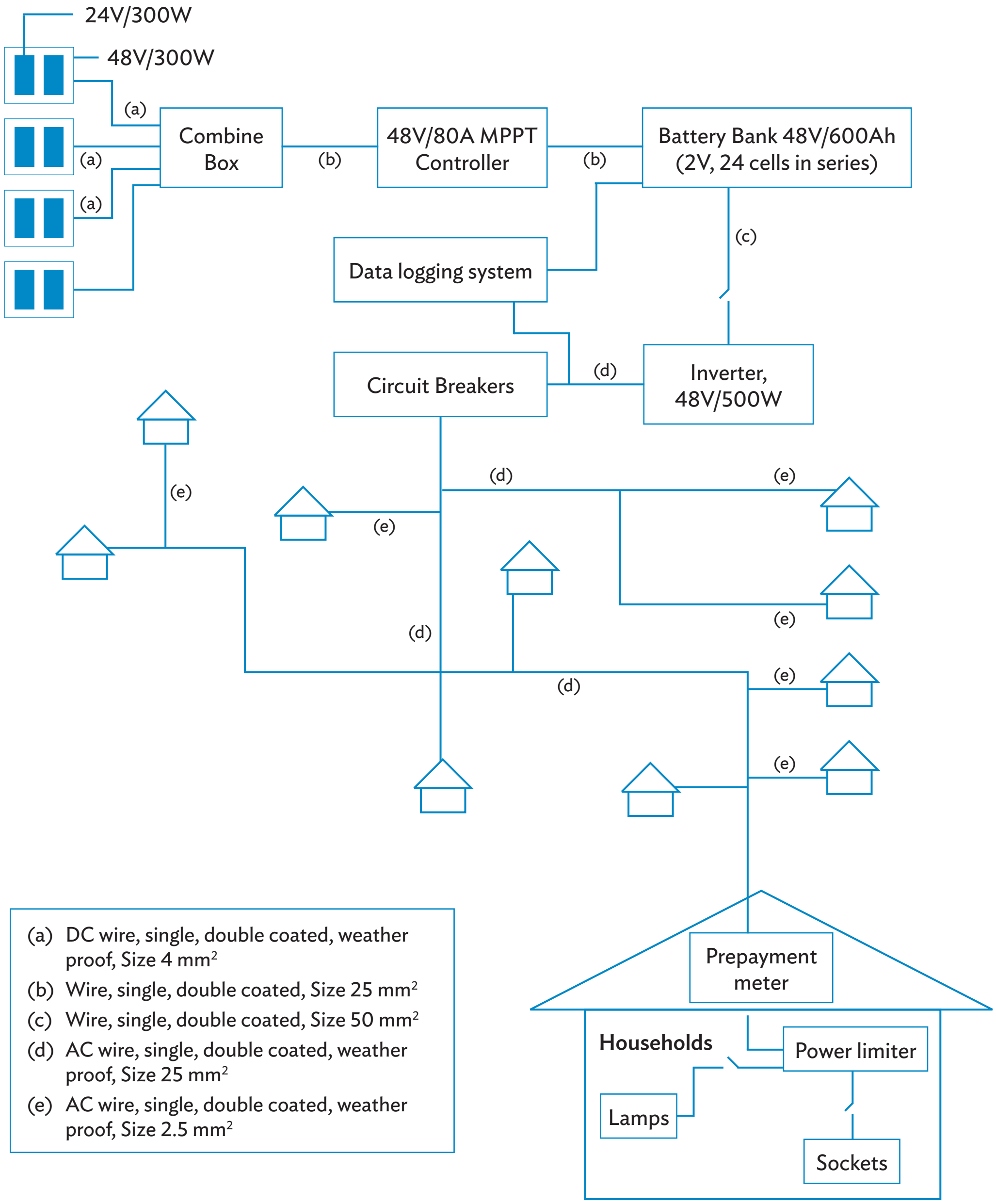
Table 6: Components of a Solar Mini-Grid for 200 Households

Component	Quantity	Unit Costs ($)	Total Costs ($)
Primary Components			
– PV modules	24	245.00	5,880.00
– PV array rack	4	350.00	1,400.00
– Charge controller	4	480.00	1,920.00
– System housing	1	1,735.00	1,735.00
– Inverters	4	1,490.00	5,960.00
– Batteries	96	225.00	21,600.00
– Data logging system	1	375.00	375.00
– Earth ground system	1	230.00	230.00
– DC wires	200	1.50	300.00
		Subtotal	**39,400.00**
Balance of System Components			
– Lamps	400	3.00	1,200.00
– Power sockets	200	3.50	700.00
– Pre-payment meters	200	48.00	9,600.00
– Power limiters	200	12.00	2,400.00
– 2.5 mm^2 single wire	6,000	0.35	2,100.00
– 1.5 mm^2 twin wire	4,000	0.45	1,800.00
– Lamp post	200	10.00	2,000.00
		Subtotal	**19,800.00**
Street Lighting			
– Stand-alone streetlights	20	790.00	15,800.00
		Subtotal	**15,800.00**
Total		**75,000.00**	

DC = direct current, mm^2 = square millimeter, PV = photovoltaic.

Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

Figure 10: System Layout for a Solar Mini-Grid



A = ampere, AC = alternating current, Ah = ampere-hour, DC = direct current, mm² = square millimeter, MMPT = maximum power point tracking, PV = photovoltaic, V = volt, W = watt.

Source: Zaburitz Pearl Energy.

System Commissioning

Once all components are installed, the system needs to be properly tested before starting full-scale operations. This is called the commissioning process. For the pilot projects, this included the following tests:

- **Combined power output test**. Inverters or DC power source need to be tested with resistive electric heater loads equal to the combined power output required (50 watts [W] per connected household) for 1 hour.
- **Solar photovoltaic array short circuit current measurement**. This is a test of solar power production under full sun. Short circuit current should match the temperature-compensated rated short circuit current multiplied by the ratio of the measured insolation to standard (1,000 W/m^2).
- **Distribution system**. This is performed by operating all connected lights and appliances (up to 100 W per household) and measuring voltage at the furthest points of each distribution point. For grid-ready AC systems, the voltage must be between 210 and 250 volts alternating current (VAC).
- **Prepaid metering system**. This is done by providing all consumers with a starting credit account balance in order to verify that all meters are operational and credit accounting and data management systems are in place with satisfactory plans for data reporting, consumer account management, and revenue collection mechanisms.
- **Data-logging system**. The proper functioning of the data-logging system needs to be demonstrated by successfully logging and retrieving at least 2 hours of data.
- **Streetlights**. Proper functioning of all streetlights needs to be demonstrated for the required minimum daily service period (for the hours from 7 p.m. to 11 p.m. and from 5 a.m. to 7 a.m.).

Inspection of the batteries in the powerhouse

Photo credit: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

2.6 Capacity Building

Capacity building to develop local skills is essential for the success of a mini-grid, in particular the training of villagers, management committees, and local technicians in the use and O&M of the system. Especially for community-managed projects, substantial efforts need to be made to build the community's capacity to properly operate and manage the mini-grid. Experience has shown that without adequate capacity building the project can easily lead to technical and financial failure.

Training should take place at multiple levels:

- **End users**. Households and other consumers need to be trained on safety aspects and the efficient use of electricity. Since women are typically benefiting the most from the electricity services, they should be specifically targeted for training activities. Training should cover basic introduction of the technology used.
- **Village committee**. Training may cover general aspects of renewable energy mini-grids and electricity services, as well as project management, including fee collection, finance aspects, and accounting.
- **Local technicians**. Training of local operators is required to ensure that they can handle routine maintenance tasks and basic repairs, and to make sure that villagers use the system correctly and that it will continue to operate in the long run.
- **Local government staff**. Training should be provided at a broader level, from basic technical aspects to electrification planning.

The capacity-building and training materials, especially those used for training of power plant operators, should be practical and adapted to the project context as much as possible. All the training materials, including equipment catalogues and O&M manuals should be translated into the local language.

Kyet Su Taw village citizens learning about the ADB solar PV mini-grid projects

Photo credit: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

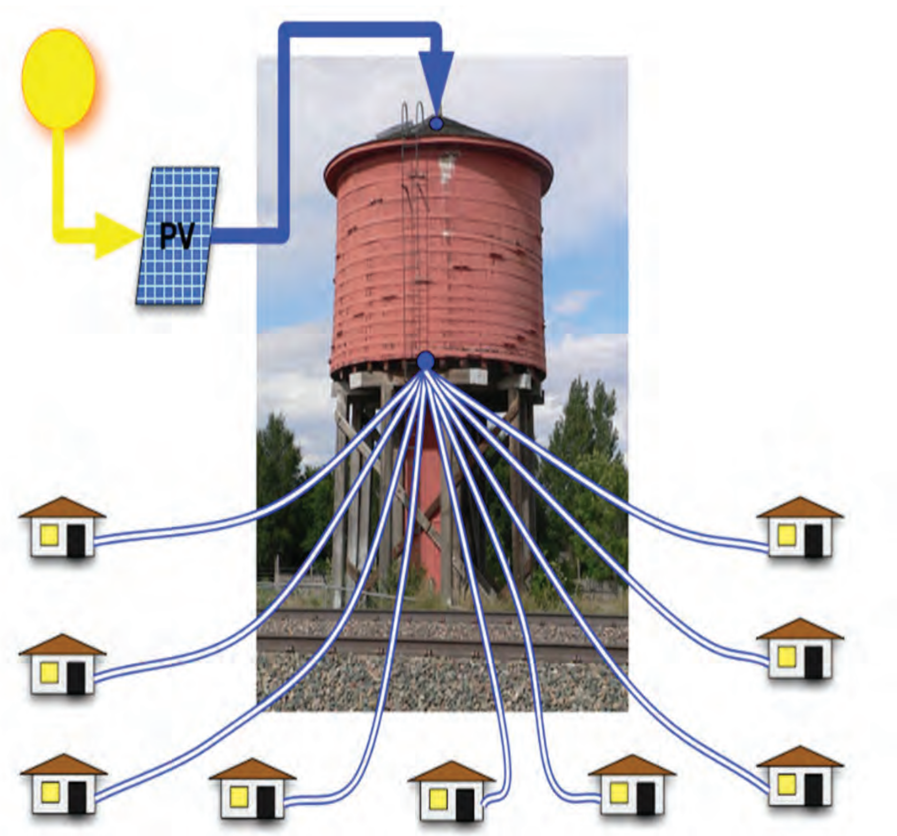
Training of Communities

Training of consumers can take several forms:

- Information meetings demonstrating use of electricity.
- Instruction leaflet to be distributed to all consumers with dos and don'ts on using electricity. Leaflets should strive to be simple without being too technical and use mostly pictures.

Since renewable energy mini-grids rely on variable resources such as sunlight or water flows, it is important to emphasize the limitations of the system and the need for efficient use of the electricity available. Using a water analogy is potentially a useful and practical way to train rural communities. In this approach, the supply, storage, and demand of electricity in a mini-grid is compared to centralized water distribution to multiple consumers (Figure 11). This helps to explain the limitation of a mini-grid and to emphasize the need to use electricity efficiently to prevent overconsumption and system failure.

Figure 11: A Solar Mini-Grid as a Central Water Tower Shared by the Community



PV = photovoltaic.

Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

During the community training of the pilot projects, different ways to demonstrate this were used:

- Bottle of water with holes of various sizes to represent various sizes of "power" consumers
- Cups of water poured into top of bottle to represent solar panel charging
- Cloth over cups to represent dust and/or dirt on the panels
- Sponges over the cups to represent clouds blocking solar power
- Water dumped out of cups to represent losses from shading
- Cups half-filled to represent lower power in the morning and evening
- Participation from trainees to play the roles of solar panels and consumers, removing pegs from holes to "turn on" loads such as lights and appliances, draining water from a bottle to represent discharge from the battery.

Villagers training on the importance of efficiency
Photo credit: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

2.7 Operation and Maintenance

Proper O&M is highly important to ensure that a project stays operational for many years. However, this aspect is often overlooked, especially in projects funded by grants, causing many projects to fail.

As the pilot projects have become operational only recently, limited experience is available from their operation. Nevertheless, the following are important considerations:

- The involvement of villagers for O&M can be highly cost-effective, but they need to be trained properly and be provided with tools and guidance to be able to handle their task.
- Even with proper training, local technicians may have insufficient technical capacity to handle non-routine issues, so there is a need for the availability of an external party that can provide maintenance beyond routine tasks and procedures.
- Installation costs should provide for basic spare parts and tools to cover basic maintenance issues to minimize shutdown periods.
- In addition, provisions need to be made for the periodic replacement of major components such as batteries. User fees should be set sufficiently high to cover this, and a reserve fund should be established to build up sufficient funding.
- In projects with multiple stakeholders (e.g., a village committee), a service provider and local government agency, ownership rights, responsibilities, and risks need to be clearly established and documented for all parties, so each knows its role and responsibilities and conflicts can be avoided.

3 Community Participation and Gender Mainstreaming in Mini-Grid Projects

3.1 Importance of Community Participation and Gender Mainstreaming

Why should local communities participate in the development of a mini-grid project?

Community participation is widely acknowledged to be crucial for the sustainability of any decentralized electrification system. Worldwide experience from mini-grid projects shows that involving the beneficiary community from the very beginning and throughout a mini-grid project will help improve the design to be optimal for the local conditions, strengthen local support for the system, mobilize community contributions in cash and in kind, and increase local spirit of ownership and responsibility—all contributing to operational sustainability. Participation of different community members, both men and women, young and old, poor and more well-off households, will moreover ensure equity in access to electricity, when various beneficiary concerns can be taken into consideration early on in the system development. Moreover, community capacity enhancement is considered one of the main factors ensuring success and sustainability in village-based mini-grid systems.

What is gender mainstreaming and why is it needed in a mini-grid project?

The lack of access to reliable energy services generally affects women more than men due to women's role in family and society. Women have to spend long and exhausting hours fetching fuelwood and water, instead of using their time on more productive livelihood activities, education, or family welfare; and women's health is affected by unhealthy indoor air with smoke from traditional cookstoves and by working in the dark on domestic tasks in the early and late hours of the day. Without proper public space lighting, women are more vulnerable than men during dark hours of the day, and they often avoid attending activities such as training classes and meetings that take place in the evenings. Access to reliable energy will therefore make a major difference in women's lives and their available time.

Men and women often have different needs and priorities, based on their different responsibilities and activities. Generally, women's primary attention is on the needs and well-being of their families; on their children's health, education, and activities; on the health and well-being of elderly family members; on the family home, kitchen, and cooking and on small income-generating activities that can add to family income. Women may therefore prioritize more lamps enabling children's school homework in the evenings and electric appliances for improving their kitchen and cooking standard over entertainment appliances that often become the priority of men after village electrification. Street lighting in the village is a high priority for women and girls, making the public space more secure for them during the dark hours.

Gender mainstreaming means that the views, concerns, ideas, and priorities of men and women, the young, the elderly, the poor, people with disabilities, and other vulnerable persons are all considered in development projects such as a mini-grid system. Consequently, different groups of people in the community will be able to benefit equally from the project.

Benefits of Community Participation

Community participation early on in a mini-grid project will result in a system that best meets the local needs and contributes to the local development. Early involvement of the end-user community will also help the system developer find out what kind of community capacity-building is necessary for sustainable long-term management of the system.

When villagers understand the concept of a mini-grid system and how it can benefit them, community support is triggered. Both as a community and individually, they will be motivated to take responsibility for the system, and manage and maintain it in the best possible way for their own benefit. The community may have ownership of the system to a certain extent, but experience shows that people's own financial and/or labor investment in the build-up of a mini-grid system will contribute to a sense of ownership and responsibility for the system and also encourage responsible electricity use.

During the pilot projects, it was noticed that earlier electrification projects with no investment from consumers had not triggered accountability in electricity use: villagers left home lights on all night because they did not need to pay for the electricity. On the other hand, in villages with meter-based electricity payment systems, people were well aware of energy costs and

Community meeting in one of the project villages
Photo credit: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

switched off the lights before going to bed in the evening. This experience emphasizes not only community ownership but also the need for awareness raising and capacity building on safe and efficient use of electricity in local communities.

Benefits of Gender Mainstreaming

Women in general spend more time than men at home undertaking domestic tasks for the family. Women can therefore be considered the experts on household energy needs. If local community leaders and male household heads are the only ones involved in the mini-grid system planning, implementation, and management, the needs and priorities of different groups of end users may not be fully considered in the design, setup, and electricity management. If women and men are equally engaged and given responsibility for the mini-grid system, it becomes equally accessible for different groups in the community. Engagement of women in management of the mini-grid system as members of the Village Electrification Committee (VEC), as fee collectors and O&M technicians will moreover enhance respect for women's knowledge, skills, and capacity, and improve their status in society. Women are also generally known to be more reliable than men as financial managers and money collectors, based on their domestic responsibility for the household budget and family welfare.

Ensuring Communication and Participation in a Mini-Grid Project

To involve the mini-grid beneficiary community, a mini-grid project developer should ensure a participatory communication process throughout the system development, installation, and operation. At a minimum, the developer should arrange regular participatory consultations with community members, build upon existing local organizational structures, and establish a community committee to manage the project and the system operation after it is installed.

There are times when project developers consider that they involved the beneficiary community when they met with local government leaders and arranged a public consultation meeting with invited household heads from the beneficiary community. These kinds of meetings often remain a one-time activity of information delivery from the project developer to male community leaders and household representatives. More often than not, the provided information is too technical and conveyed using communication methods and language that are hardly understandable for poor rural people. After such meetings, participating community members have difficulties remembering the information and they cannot share it with their families and other villagers.

What is participatory communication?

Participatory communication is more than a public consultation meeting. Communication is ideally an activity with two or several parties sharing information with each other, listening to each other and, importantly, also understanding and responding to each other's views, opinions, and concerns. Communication is not a one-time activity but should take place throughout all project phases. Two-way communication is crucial for building mutual understanding and trust that will form the foundation for cooperation between different involved parties and contribute to project effectiveness and sustainability. Not only will this keep the local people as future electricity consumers informed, but the mini-grid developer will also learn important information from the community that will contribute to a sustainable

Villagers after a meeting in one of the project villages
Photo credit: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

mini-grid system. Communication will enable the participation of different involved parties in the project.

What is participation?

Participation is a process in which different parties that are involved in a mini-grid project can influence and contribute to the planning, design, implementation, and monitoring of the project, and therefore also influence its outcome. It is a process that should start early in the project planning and continue throughout all project phases and into the operation of the mini-grid. The participation process must allow all parties to be heard and for the project developer to respond to their experiences, opinions, and suggestions.

3.2 Community Involvement in Different Phases of a Mini-Grid Project

Mini-Grid System Planning and Design Phase

Mini-grid system developers should never approach a local community with intended future electricity consumers with a predefined, fixed mini-grid project without any adaptation potential. They should be flexible to discuss the mini-grid plan with the local community members, listen to their ideas and concerns, and adapt the system to meet the needs and expectations of the end-user community to the greatest possible extent.

Project developers should identify the local social and organizational structures, and involve local authorities and leaders who are in a position to influence local opinion on the mini-grid project early on in the project planning phase. Added to persons in power position, it is important to involve any active civil society organization and to ensure representation from all potential electricity customer groups, such as local shops and other small businesses, monasteries, public services like health clinics, schools and government offices, and all households in the village.

Representation of women has to be ensured through any existing local women's groups, and by inviting not only the household head (who in general are men) but both the husband and wife of each family into meetings about the mini-grid. When organizing meetings with local community members, it is important to consider a time and place that is accessible to all community members. For example, planning meetings should not be organized far away from the village (when the participation of women and the poorest households is usually crucially reduced) or during the most active agricultural season when most people are too busy to attend any extra meetings.

In the planning and design phase, at least the following issues need to be discussed, clarified, and agreed upon with the end-user community:

(i) current and future energy demand;
(ii) willingness to pay;
(iii) community commitment to the project;
(iv) community organization for management of the mini-grid (if the system is intended to be owned and/or managed by the local community) as well as possible need for support and/or assistance for funding a community-owned mini-grid; and
(v) potential legal and common rights issues (e.g., land ownership, rights, rights of way).

Mini-grid project developers should initiate a communication process with the local community early during the planning and design phase of a mini-grid system:

(i) It is most often beneficial to first meet with the local leaders as well as representatives of civil society organizations, local public services, and local businesses to introduce the project idea and design in order to win their support for the planning.
(ii) After involving the local opinion leaders, the project developer should cooperate with them to organize one or several community meetings inviting all potential future electricity consumers. This meeting should provide general information about the mini-grid system, its benefits, basic design and capacity, and expected costs for the community and for end users. It is important for information to be provided in a clear and understandable way for the local community members. Technical details usually are not comprehensible for rural small farmers with little formal education, but they should be provided with relevant information such as how many lamps and electric appliances the system will allow for each family, small business, and public facility, whether street lighting can be included, and how much (in kyat) the system setup and electricity use will cost the community and the individual households. It is important to be clear about the capacity and costs of the system and not to raise false expectations among the local community members. Experience from the Off-Grid Renewable Energy Demonstration Project shows that if the financial contribution and

tariffs are not stated clearly in kyat, local communities may decide against financially committing themselves for an electrification system with investment costs.

(iii) If possible, the mini-grid project developer should collect more specific information about the different future electricity consumer groups, their needs, expectations, and plans for using electricity. Small focus-group meetings (ideally no more than 10 persons) can be arranged to discuss their specific ideas and concerns, for example, with separate groups of men and of women, of small business owners, and of government staff. The developer may also consider undertaking a household survey for mapping household electricity demand.

(iv) The required local management organization for the mini-grid should be discussed and agreed with the local community. It is crucial to build upon the existing organizational structures in the village. The roles and responsibilities of the village electrification or mini-grid management committee, electricity fee collectors, as well as the local O&M technicians to be selected and trained among community members should be made clear, discussed, and agreed upon to establish a local model for the required organization. The management organization should be representative of the entire community and different groups of people, such as being gender balanced with an equal number of men and women. The Off-Grid Renewable Energy Demonstration Project provides good experiences of gender-balanced village organizations and both male and female O&M technicians in every project village.

(v) Already in the initial community meeting, a small gender-balanced management group representing the community should be chosen as a communication bridge between the village and the project developer. Once the local community has become aware of the potential mini-grid project, community members need time to discuss within the community and raise their questions and concerns, which preferably can be conveyed to the project developer through the village management group. This group can also take responsibility for arranging meetings with villagers to discuss the mini-grid system if needed. Smaller meetings with different groups of people, such as with women only, local small business owners, and local public service providers, may provide an opportunity for people to discuss their specific questions and concerns. The village management group may also call for a meeting with the project developer whenever it is considered necessary. This community representative group may be temporary or preferably developed into a community mini-grid or electricity management group.

(vi) If possible, local future electricity consumers should be provided with brief written and pictorial information about the planned mini-grid system, containing basic information about its setup, its capacity and potential for the end users, and the cost level for a certain number of lamps, mobile phone charging, and standard electric appliances such as fans, TVs, refrigerators, and so on. The required community management organization should be explained as well. This information can be provided in a poster set up in a central place in the village (such as a community meeting hall) or in leaflets delivered to every household, public facility, and business.

(vii) In the planning and design phase, the project developer should also provide awareness-raising information to the local community on the efficient use of energy and the potential productive use of energy. Responses from the community may then lead to adjustments in the system, based on the estimated local future electricity demand.

(viii) During the course of the planning phase, the mini-grid developer should find out what kind of consumer capacity-building is needed among the end users for the safe and efficient use of electricity. The developer also has to identify what kind of management, financial, and technical training is required for the efficient functioning of the village electricity management committee, electricity fee collectors, and village O&M technicians. Relevant specific capacity-building and training programs have to be designed based on the existing capacity and development potential in the community and among the community members with special tasks in the village electricity system management. Experiences from other villages already operating mini-grids can be used in the design of the capacity building program.

(ix) All communication with villagers should take place and the information content should be at a level and using language that is understandable for people with little formal education. It is important to avoid difficult technical information and special terminology. Instead, relevant questions for the consumer community should be dealt with. Communication should be culturally appropriate and respect the social organization in the specific local community. Feedback mechanism from the community to the project developer should be made clear so that all villagers know how to raise their concerns and further questions. A village management group is an ideal instrument for regular and continued two-way communication between the mini-grid project developer and the local community.

Implementation and Construction Phase

It is important for the project developer to continue regular two-way communication with the local community during the construction phase of a mini-grid system. Communication should take place through regular community meetings or at least through the village management group.

At the latest during the construction phase, the village mini-grid management organization should be in place. Based on and respecting the local organizational culture and customs, villagers will choose representatives for a village electricity management committee, as well as responsible persons to be trained as electricity fee collectors and as mini-grid system O&M technicians. Men and women alike should be chosen for these tasks, and financial issues such as salaries for the villagers with special roles in the mini-grid system operation have to be agreed upon.

During the mini-grid construction phase, consumers, village electricity management committee members, electricity fee collectors, and O&M technicians should undergo the capacity building training as designed during the planning phase. It is crucial for the key persons in the village, the management committee members, and the O&M technicians to be fully involved in the mini-grid construction and gain understanding of the system and its functioning at a level required for the daily O&M and minor troubleshooting. The mini-grid developer has to ensure that all training is at an appropriate level for the trainees to fully benefit from the capacity building for a sustainable management and O&M of the village electricity system.

A further effective method of providing support to new village management committees and technicians is to invite "mentors" from other neighboring villages with experience of a mini-grid operation, if available.

Operation and Maintenance

Ideally, participatory planning and design of a mini-grid system added with capacity building and special training during the implementation phase will ensure a smooth operation and consumer satisfaction in the village. When the mini-grid is put into operation, the village electricity management committee will be responsible for coordinating any information and consumer feedback that may be needed for service, later system upgrades or adaptations, and so on. Feedback mechanisms between the village committee and the mini-grid developer should be clearly agreed. They should also agree on regular refreshment training and support provided by the mini-grid developer to village technicians and management committee members for keeping up their capacity.

The local community may need support in developing new livelihood options that are made possible with electricity access. Assistance needed may include finding sources of funding, capacity building, or technical equipment, which the mini-grid developer may be able to add to the mini-grid project. Especially if a government agency or a nongovernment organization is involved in a mini-grid project, a livelihood development program may be integrated into a village electrification project.

3.3 Impacts of the Pilot Projects

After the installation and commissioning of the pilot projects, a survey was undertaken in half of the 12 villages to collect feedback from the villagers on the impacts of the pilot projects. The following summarizes the main findings.

Women's Lives

- Cooking and other household tasks have become much easier, especially during the early morning hours before daylight.
- Income has increased due to the possibility of working longer days and extra hours during the evening, e.g. peeling tamarind, peanuts, and chili.
- It is safer to move around in public places after dark thanks to street lighting.

Education

- Children are able to do their homework at home in the evenings thanks to proper lighting.
- Classes in the schoolhouse can continue in the evening.

Safety and Health

- Thefts of livestock have been reduced; villagers can better keep an eye on their animals.
- Fires and accidents caused by candlelight and kerosene lamps have been reduced; parents need not worry over their children playing with candles and kerosene lamps.
- It is safer to move in the village after dark, e.g., to go to the pagoda, attend meetings, or visit neighbors.

- Incidents of snake and insect bites have reduced as snakes, scorpions, and other creatures can be seen at night.
- Health care staff are more easily available for emergency patients during the evening.

Life Quality, Information, and Entertainment

- Watching TV is entertaining (e.g., football, films, and shows) and also contributes to villagers being better informed through news and documentary programs.
- Mobile phones can be charged, and especially young people can enjoy communicating online.
- With lighting in the village meeting hall, monastery, library, and other public spaces, it is easier to arrange different activities in the evenings.

Streetlight in one of the pilot projects

Photo credit: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

4

Summary of Lessons Learned from Pilot Projects

The following summarizes the main lessons learned from the implementation of the 12 pilot projects:

- Community engagement was considered one of the most critical elements by the different parties involved in the pilot projects. The development of the projects required multiple rounds of discussion with villagers to explain the benefits and contributions from the community, as well as contract negotiations. The vendors were able to rely on third-party support from Suntac and Department of Rural Development (DRD) to facilitate these discussions, which they considered highly instrumental. Without such support, projects would have been much more difficult and costly to implement.
- The level of community organization prior to the pilot projects clearly affects the potential for mini-grid development. DRD has been implementing a village-level microfinance facility, called Evergreen, under which villages receive funding that establishes a revolving fund, which villagers can use for a variety of purposes. It requires sufficient village cohesion and villagers to jointly manage a village fund. In addition, like in the pilot projects, there needs to be gender balance in the managing committee. The program has been instrumental in strengthening village cohesion, building capacity to manage community funds, and enhancing gender balance in decision-making committees. This greatly benefited the implementation of the pilot projects in those communities with prior Evergreen experience. Also, in villages with Evergreen, it was easier to reach an agreement. Out of the 12 pilot projects, 6 had previous experience with Evergreen.
- Obtaining and maintaining villagers' interest in participating in the project can be a major challenge. A fairly large number of villages were not interested or able to participate, and alternative villages had to be found to replace villages that withdrew after initially expressing interest. Therefore, programs or developers targeting multiple villages should identify a sufficiently large number of villages from an early stage so that replacement villages can be identified if needed. In addition, the process of procurement, installation, and commissioning of mini-grids once the village confirms its interest should be as short as possible to maintain interest.
- Accessibility also strongly affects the feasibility of a mini-grid. Some communities were rejected because of poor access. In some projects, system installation was delayed for several months due to road conditions. It should also be considered that during the rainy season certain communities are hard to visit for follow-up.
- Incomes of rural communities are highly seasonal. This affects the collection of the village contribution and possibly usage fees. Payment collection mechanisms should take this into account and allow for payments to be made in a flexible manner (e.g., during harvesting season).

- Across Myanmar, there are already numerous mini-grids in operation powered by diesel generators. Renewable energy technologies can be employed to create hybrid systems that would lower the cost of generation. Nevertheless, as shown by the hybrid pilot project implemented, these existing diesel generators may be of too poor a quality to develop truly hybrid systems.
- Sufficient technical capacity exists within Myanmar for the installation of high-quality mini-grids according to high safety and performance standards. The two solar companies that were awarded the contracts to install the mini-grid systems delivered good quality work.
- Streetlights are highly appreciated by villagers for improving nighttime security. Benefits include more social interaction after dark, reduced snake bites due to the ability to see snakes on the road, and reduced livestock theft. In most of the pilot sites, villagers requested additional streetlights after initial installation and were willing to pay for the additional costs.
- The potential for further mini-grid development in the Dry Zone is large, particularly in Magway and Sagaing regions. In Magway Region, many areas are not connected to the grid and renewable resources are available. Sagaing Region has the largest potential as the state is quite large, with rather small coverage of the grid and a vast resource potential. For Mandalay Region, the overall potential is much smaller as the power grid covers already large areas of the state, leaving only a limited number of suitable locations for off-grid investments, which are often either quite small or close to the existing grid.
- However, at present, there is no regulatory framework in place that addresses what happens when the grid arrives at villages with mini-grids. Uncertainty about grid expansion creates financial risk for mini-grids or similar models.

5

Renewable Energy Technologies for Mini-Grids

This section discusses the main renewable energy technologies that are suitable for mini-grid development in Myanmar.

5.1 Solar

Solar photovoltaic systems use sunlight to directly generate electricity. Solar systems are highly versatile and can be used for various applications, such as rural electrification of single households with solar home systems, stand-alone or grid-tied mini-grids, solar farms that sell power to the grid, rooftop solar to power offices and factories, as well as traffic signals and communication towers in remote areas. Installation costs have decreased significantly over the last decade, and solar has become cost-competitive compared to conventional technologies in many countries and situations.

Technology

A solar photovoltaic panel converts solar irradiation into electrical energy. The panel generates maximum energy when the sunrays are perpendicular to its surface so its actual output varies highly depending on the season, latitude, and time of day. Production also depends on local weather conditions such as air humidity, dust, and cloud cover. The photovoltaic panels should be installed at an optimal angle for maximum sunlight exposure.

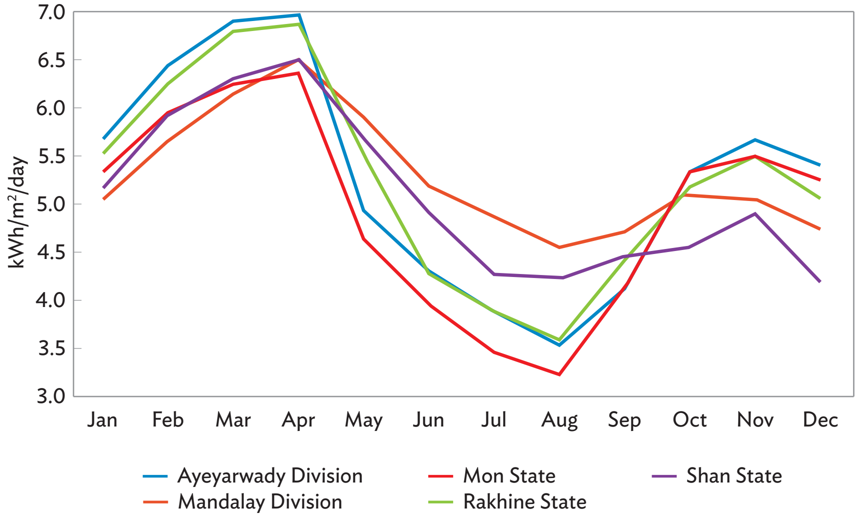
It is important to note that solar resources can vary widely by location and season. Figure 12 shows the variation throughout the year for selected areas in Myanmar. This shows that during the peak of the rainy season in August, solar resources are roughly half of the solar peak in April. The design of a solar mini-grid system should take these variations into account, by choosing the appropriate capacity of the solar panels and batteries.

Assessing the available solar resource is an important first-step to investigate the potential for a solar mini-grid. The characteristics of the solar resource, the local climate and weather patterns all determine the suitability of the system configuration, technology choice, and project economics. Therefore, having access to good quality, high-resolution solar resource data is critical. This can be obtained through several methods:

- On-site measurements,
- Data from nearby weather stations, and
- Satellite data.

Designing a solar mini-grid system is a complicated engineering task, and an improper design will affect the system's technical performance and economic feasibility.

Figure 12: Solar Insolation for Selected Areas in Myanmar



kWh = kilowatt-hour, m² = square meter.

Source: Assessment of Solar Energy Potentials for Myanmar, Department of Alternative Energy Development and Efficiency, Thailand (2009).

Key Components

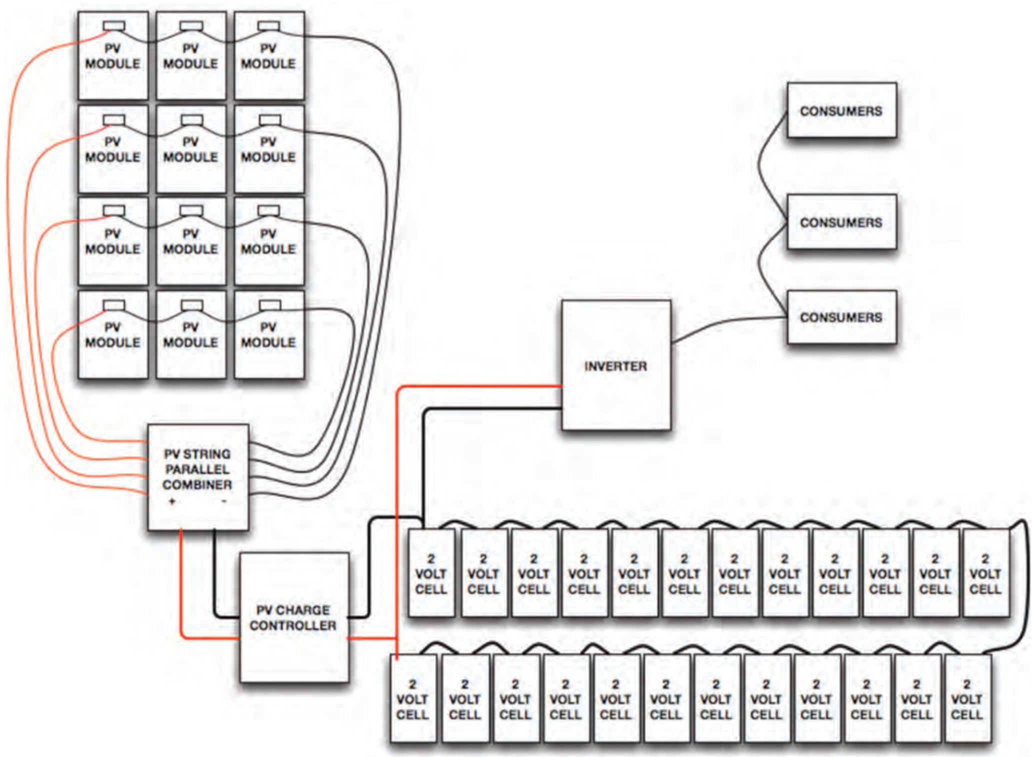
A solar mini-grid system typically includes the following main components:

- **Solar panels**. These generate electricity in the form of low-voltage direct current (DC). Mini-grid systems use multiple panels. They should be placed with an orientation facing South to capture maximum sunlight. In Myanmar, this is typically at an angle of 15–25 degrees. The panels should be installed in a location with minimal shading throughout the day.
- **Batteries**. These should be deep-cycle type batteries, specifically designed for photovoltaic systems. While more expensive than car batteries, they last much longer and are more cost-effective in the long term. Batteries are typically the weakest element of a system and require adequate maintenance.
- **Charge controller**. This prevents overcharging and deep discharging of the batteries.
- **Inverter**. This converts low-voltage DC power to higher-voltage alternating current (AC) power. Larger systems may have more than one inverter. Small mini-grids that operate on DC power do not require an inverter.
- **Balance-of-system components**.
  - **Mounting racks**. These are used to fix the solar panels at the right angle, either on the ground or on a roof. These should be made of corrosion-resistant materials.
  - **System housing**. This is a weatherproof metal enclosure to house the batteries and electric equipment. For larger systems, a masonry "powerhouse" may be constructed instead.
  - **Wires and conduits**. These need to be sized to cause minimal voltage drop and line loss.

- **Circuit protection**. This consists of fuses and circuit breakers to prevent damage to the system. Note that all wires connected to batteries need circuit protection.
- **Earth grounding**. This is for lightning protection and safety from shocks and ground faults.
- **Consumer loads**. These include lights, TVs, and fans.

The basic layout of a solar mini-grid system is illustrated in Figure 13.

Figure 13: Basic Layout of a Solar Mini-Grid System



PV = photovoltaic.
Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

The different components available in the market can vary highly in price and quality. Use of cheap, low-quality equipment can lead to system failures, lower output than expected, a shorter lifespan, as well as the need for additional maintenance. High-quality components will cost more but have a longer lifespan and maintain their performance level better over time, ultimately improving project economics. For example, high-quality (Tier 1) solar panels come with a 25-year warranty on the rated output.

Appendix 1 contains an example of the technical specifications for one of the pilot projects, with more details on the typical requirements for the key components of a solar mini-grid system.

Strengths and Constraints

Every technology has strong and weak points in its application. The following highlights the main strengths and constraints of the use of solar for mini-grids.

Strengths

- Solar mini-grids can be installed as modular systems. They can be easily expanded if the demand increases over time and there is a need for additional generation capacity.
- Compared to other technologies, solar mini-grids have a short development time and can be installed in only a few months. Systems can also be easily moved if needed.
- Costs of solar systems have decreased significantly. Mini-grids that aim to provide basic energy services to households can be installed cost-effectively.
- Solar photovoltaic panels have a long lifespan and top-tier quality panels typically have a 25-year warranty on performance.
- Operation and maintenance (O&M) is fairly straightforward and can be handled relatively easy at the village level. There are no moving or rotating components that require higher maintenance.

Constraints

- Solar systems generate electricity during the day, while villagers mostly use energy in the evening. This means that the electricity needs to be stored before it can be used. Solar systems use deep-cycle batteries for storage, which are fairly expensive and need to be replaced every 3–5 years.
- Solar mini-grids can provide only limited power capacity and are suitable for basic energy services to households, such as lights, phone charging, and fans, for a limited number of hours in the day. They are less suitable for higher loads such as rice cookers, 24-hour services, and productive uses, such as milling.

5.2 Hydro

Hydropower is a technology for generating electricity from falling water. It is a major power source in many countries and the most established renewable energy technology for electricity generation, with numerous hydropower plants in operation worldwide.

Technology

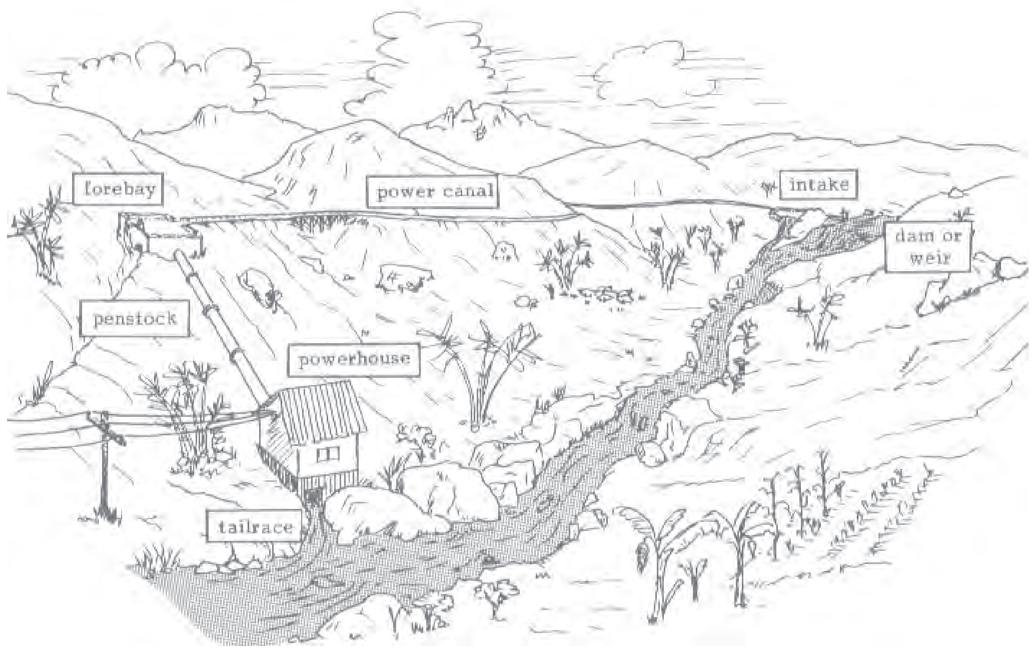
There are two main design types for hydro projects:

- **Storage system**. A dam in the river blocks the river flow and causes a large accumulation of water by flooding the valley upstream, with large impacts on the river ecology. This type is also used for seasonal storage and flood prevention. A common problem with large dams is the accumulation of silt.
- **Run-of-the-river**. A diversion weir installed in the river diverts a portion of the water flow for power generation, after which it will be returned to the river. This causes minimum impact to the river as it does not affect the seasonal flow pattern

downstream. Run-of-the-river is the most common type in the context of mini- and micro-hydropower (Figure 14).

Hydropower plants can also be categorized according to installed capacity (Table 7).

Figure 14: Basic Run-of-the-River Hydro Scheme



Source: Inversin (1986).

Table 7: Hydro Classification by Capacity

Term	Capacity	Application
Pico hydropower	< 500 W	– For a single or a few households – Only suitable for isolated operation – Usually very maintenance intensive
Micro-hydropower	0.5–100 kW	– Power supply for several hundred households – Mostly for isolated micro-grids for rural electrification – Grid connection possible
Mini-hydropower	100–1,000 kW (= 1 MW)	– Power supply for up to several thousand households – Promising potential on smaller rivers – Can contribute to grid stabilization, especially at end points – Larger-scale productive use possible (e.g., tea factories)
Small hydropower	1–10 MW	– Power supply for several ten-thousand households – Promising potential on medium-sized rivers – Can contribute to grid stabilization
Full-scale (large) hydropower	> 10 MW	– Power supply for large cities and supply to national grids

kW = kilowatt, MW = megawatt, W = watt.

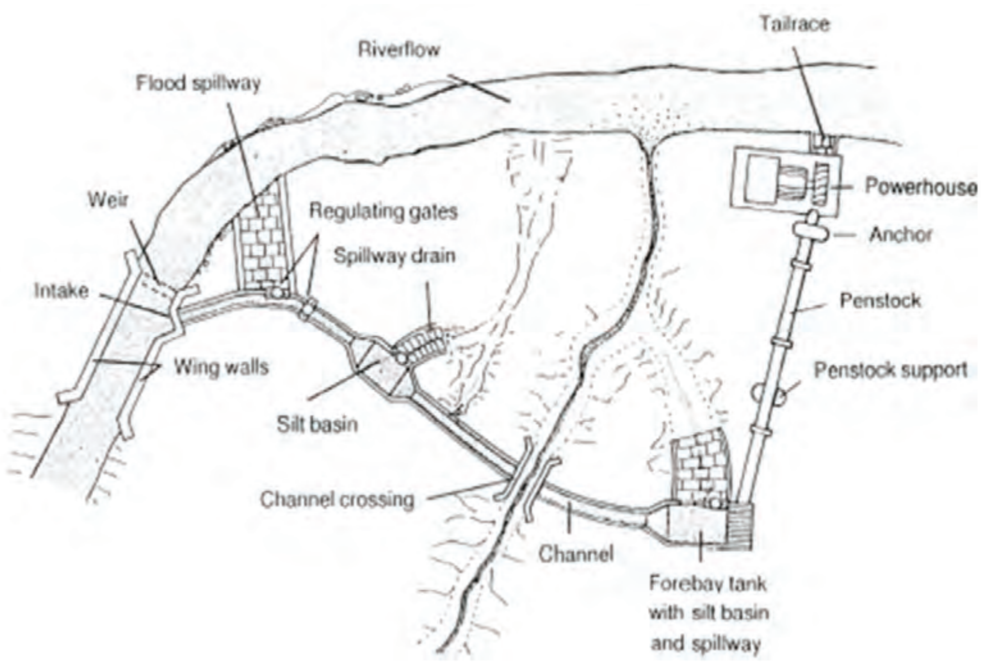
Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

Key Components

A hydropower plant employs a combination of civil works and electro-mechanical equipment to harness energy from a river's water flow. The following are the key components of a micro-hydropower project (see also Figure 15):

- **Intake**. Takes water from a river or a pond and delivers it to a canal, penstock, or storage basin. The intake must be able to operate under wide fluctuations in flow levels and handle large quantities of silt, sand and gravel, or floating debris such as branches and leaves.
- **Power canal (or head race)**. Conveys the water from the intake to the desilting basin. The headrace can have any length from 0 (if the penstock starts at desilting basin) to several kilometers. An open channel is often the most cost-effective solution, but in cases of crossings, or unstable and/or steep ground, pipelines should be used.
- **Desilting basin**. Traps and eliminates sand and silt from the diverted water, to prevent damage to the turbine and obstruction of the water flow.
- **Forebay**. Serves as a final settling basin for suspended matter in the water and provides submergence for the penstock inlet (to avoid air entrainment). The forebay must have a minimum storage volume to accommodate rapid changes of turbine flow, typically corresponding to 30 seconds of turbine design flow. In some cases, an enlarged forebay serves as daily storage to cover daily peak demands.
- **Penstock**. A high-pressure pipe that delivers water from the forebay to the turbine.
- **Turbine**. Converts the energy in the water flow to mechanical power. There are many different types of turbines, and the choice depends on the height drop and flow.

Figure 15: Components of a Run-of-the-River Hydropower Plant



Source: GIZ (2016).

- **Generator**. Driven by the turbine, generating electricity. There are three main types (synchronous, induction or asynchronous, and permanent magnet) and the choice depends on several factors (e.g., stand-alone or grid-connected, single- or three-phase, voltage level).
- **Electronic load controller**. Ensures that electricity frequency remains stable under fluctuations in electricity use.
- **Powerhouse**. Houses the turbine, generators, control room, etc. Powerhouses must be situated well above expected flood height and on the inside of stream bends.
- **Tail race**. Outlet to return water to the stream after passing through the turbine.

Mini- and micro-hydro projects can employ a wide range of designs and materials for the civil works, in contrast to concrete and steel-intensive structures used in large hydro projects.

Estimating Potential Capacity

The installed capacity (or maximum potential power) of a hydropower plant is a function of:

- gravity constant: a fixed value of 9.8 meters per second (m/s);
- efficiency: reflects the conversion losses in energy generation;
- head: height difference between the forebay and the turbine, measured in meters (m); and
- flow: the volume of passing water, expressed in liters per second (l/s).

The potential capacity, expressed in watts, can be calculated as follows:

$$\text{Power} = 9.8 \times \text{Efficiency} \times \text{Head} \times \text{Flow}$$

For example, a project with a head of 30 m, a water flow of 200 l/s and efficiency of 70%, will have a capacity of about $9.8 \times 0.7 \times 30 \times 200 = 41{,}000$ watt, or 41 kW.

Different methods exist to measure the head for a particular site, ranging from simple, hands-on techniques such as "measuring stick and water-filled tube" to sophisticated laser-leveling measurement equipment. Likewise, there are different methods to measure the flow of a stream. Regardless of the methods chosen, it is crucial to take on-site measurements during different periods of the year to account for seasonal variations.

Strengths and Constraints

Strengths

- The levelized cost of electricity from mini- and micro-hydropower plants is typically low compared to other options. The levelized cost of electricity is a measure of the cost of electricity generation over the lifetime of the project (see also Appendix 2).
- The output from a hydropower plant has a fairly high level of predictability, with only a slow rate of variation in water flow and power generation from day to day (not from minute to minute).
- Hydro is a proven, long-lasting, and robust technology. If properly designed and built, a mini- or micro- hydropower plant can last for 50 years or more.
- O&M is fairly straightforward and can be handled relatively easy at the village-level.

Constraints

- The design of a hydropower plant requires a considerable amount of specialist know-how, which is not always locally available. It should be noted that micro-hydro is not simply a scaled-down version of large-scale hydropower but uses unique design and construction techniques.
- Community micro-hydro schemes require sustained effort for O&M, which rural communities are not always able or willing to provide, for example, due to lack of organizational capacities or budget constraints.
- Hydro requires a suitable site and thus is highly site specific. If the stream is located too far from the community, the connection cost may become too high.
- The output from a hydropower plant is highly seasonal and fluctuates from season to season. System design should take this into account and ensure that the plant can operate throughout the year or that the community can accept lower power output during dry times.
- Rivers and streams are typically under the government's jurisdiction, so their use for hydropower may require several permits and licenses. It is highly crucial to assure that the project has all of these in place before the start of construction.
- Because hydro systems are very site specific and often located in remote areas, it is not uncommon for project costs to increase significantly during construction because of unanticipated factors in the terrain, or delays and setbacks caused by severe weather conditions.

5.3 Biomass

Biomass energy refers to energy derived from solid, combustible organic material. This may include wood, wood waste, rice husk, corn cobs, straw, manure, and many other by-products from a variety of agricultural processes. Biomass energy applications range from household cooking to multimillion-dollar projects feeding power into the grid.

Resources

There are many types of biomass, and each has different properties such as heating value, moisture content, and mineral content (Table 8). These can affect the combustion process, so the technology chosen for a particular application should be suitable for the biomass used. For example, rice husk has a high silica content, which can lead to scaling, abrasion, and corrosion in the equipment.

The long-term security of biomass supply is by far the most critical factor for a biomass project. For projects based at agro-industries such as rice mills, this may be somewhat less critical, as long as the underlying business is in operation. For projects that intend to source biomass elsewhere, it is crucial to closely review factors such as current uses, seasonal price fluctuations, potential future demand, as well as logistics and transportation costs.

Table 8: Typical Biomass Fuel Characteristics

Sector	Residues	Heating Value (MJ/kg)	Moisture Content (% wet basis)	Mineral Content (% dry basis)
Rice	Rice husk	13–14	9–12	20
Sugar	Bagasse	7–8	45–50	3–4
Palm oil	Fresh fruit bunch Fibers Shells	7–8 10–11 17–18	45–50 38–40 22–25	5.5 5.8 2
Wood	Shavings, off-cuts, etc.	11–12	30–35	1–2

kg = kilogram, MJ = megajoule.
Source: EC-ASEAN COGEN Programme.

Technology

Various biomass technologies exist, of which direct combustion and gasification are the most relevant for mini-grids. The most suitable technology for a particular project depends on many factors, such as project size, availability and cost of biomass, alternative fuel cost, scale of operation, and off-take.

Biomass systems are sensitive to fuel quality fluctuations and require adequate O&M procedures. The fuel needs to be supplied regularly and at the right specifications (e.g., size and moisture content), and the equipment requires regular inspection and cleaning. The overall process efficiency can be improved by drying the biomass before combustion, but this may not be economically feasible due to the additional costs.

Regardless of the technology, biomass projects generate solid, liquid, and gaseous waste that, if not adequately controlled, can harm the environment. Appropriate measures should be taken to minimize harmful emissions and comply with environmental regulations. These include proper operational procedures and emission control systems.

Direct Combustion

Direct combustion systems burn the fuel in a furnace or boiler to generate steam, which subsequently drives a turbine and generator for electricity generation. In essence, the technology is very similar to conventional coal-fired steam-turbine plants, with a combustion system suitable for biomass.

Cogeneration is a special type of direct combustion, in which the steam is extracted from the turbine to be used for industrial processes. In case there is a need for process steam, this can greatly increase the system's overall efficiency.

Direct combustion and cogeneration of biomass are well established and proven, with numerous plants in operation throughout the world, including in Southeast Asia. For example, sugar mills traditionally use the bagasse left over from sugar milling to generate steam and electricity to operate the mill. More recently, sugar mills in some countries have upgraded their power generation system to sell excess power to the grid.

Direct combustion and cogeneration are generally used for power projects of more than 2 megawatt (MW), while smaller systems are typically not economically viable. Biomass power plants using direct combustion require about 1–2 tons of fuel per megawatt-hour of electricity, depending on the type of fuel, scale of operation, and system efficiency.

Gasification

Gasification is a thermochemical process that burns solid biomass under a restricted supply of oxygen, which produces a combustible gas, commonly called "producer gas." The gas can be used in a gas burner for direct heat applications, or in an engine for mechanical applications or power generation. Biomass used for gasification should be fairly dry, such as wood chips, charcoal, corn cobs, rice husk, and coconut shells.

Compared to direct combustion, gasification is less mature and its application is not yet as common. A major bottleneck is that the gas typically has high concentrations of tar, which requires extensive cleaning before being fed into an engine or generator. Another issue is that the waste products such as ash and wastewater can be toxic and need to be properly treated and disposed, which can be costly and is often neglected for smaller systems. Nevertheless, significant technological developments have taken place in recent years and gasification is potentially an attractive option for small to medium-sized agro-industries, such as rice mills, with a steady supply of biomass and the need for reliable and affordable energy.

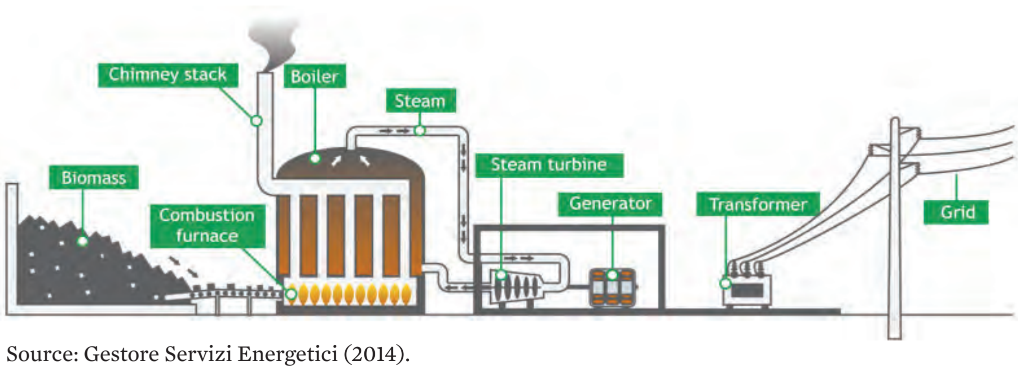
Key Components

Direct Combustion

A direct combustion system for power generation is made up of several key components, usually including the following items (Figure 16):

- **Storage**. Could be in the form of a bunker or silo for short-term storage and an outside fuel yard for larger storage.
- **Fuel preparation and processing equipment**. The biomass may need to chipped or dried before use.

Figure 16: Direct Combustion Steam Turbine System Layout



Source: Gestore Servizi Energetici (2014).

- **Furnace and boiler**. Biomass burned in a combustor or furnace generates hot gas that is sent to the boiler to generate steam.
- **Steam turbine and generator**. Steam is expanded to drive the turbine and generator.
- **Condenser and water treatment system**. Used to recover steam from the turbine, after which it is treated and reused for steam generation.
- **Exhaust and emissions controls system**. Might include a cyclone or multi-cyclone, a baghouse, or an electrostatic precipitator to remove particles.

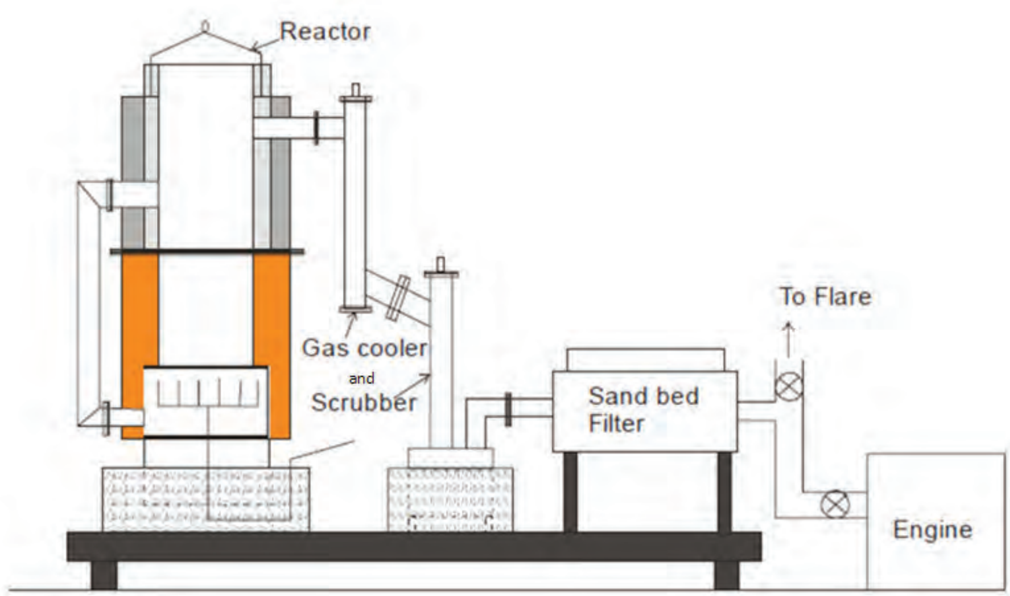
Gasification

A biomass gasification system consists primarily of a reactor in which the biomass is converted into gas, and associated equipment such as ash removal, scrubbers, and gas filters (Figure 17).

After the conversion of the solid biomass into gas in the reactor, the remaining char and ash are removed at the bottom of the gasifier. The hot gas coming out of the reactor is suitable for direct combustion in a gas burner. However, for engine applications, the gas needs to be cooled down and cleaned as it contains significant amounts of tar, soot, ash, and water.

Gasifiers are rather sensitive to fuel quality fluctuations and require adequate O&M procedures. The fuel needs to be supplied regularly and at the right specifications, and filters require regular cleaning.

Figure 17: Basic Gasification Scheme



Source: Sridhar et al. (2014).

Strengths and Constraints

In the context of mini-grids, biomass energy has a number of strengths, as well as constraints.

Strengths

- Biomass can be collected, purchased, and stored in advance, and electricity generation can be timed to coincide with use.
- If sufficient feedstock is available, a biomass plant can provide more than basic services and can power productive uses as well.
- Biomass is a suitable option for mini-grids in combination with a central source of feedstock and a need for electricity (e.g., at rice mills).

Constraints

- The availability and price of biomass change from season to season. Over the lifetime of a project, the feedstock may even become unavailable or too expensive, so the project may not be able to operate or become financially unviable.
- Due to fuel transportation costs, a biomass plant needs to be located relatively close to the fuel source. Likewise, the size of a project is limited by the availability and logistics requirements of biomass supply. Because biomass is bulky and low density compared to fossil fuels, it is not commercially feasible to transport it over large distances.
- O&M requires skilled and well-trained operators to run the plant properly, which may not be available in rural communities.
- Biomass plants require a sufficient and stable water supply for their operation, so they may not be suitable in dry areas.
- Gasification technologies currently commonly used in Myanmar tend to be low quality with little regard to pollution

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Online Resources

Microgrid Executive MBA Training – Self Study: Comprehensive, data-driven online business course on microgrid project development, including the evaluation of project economics, in a variety of markets using case studies, financial models, and templates.

https://www.heatspring.com/courses/microgrid-executive-mba-training

GIZ Mini-Grid Builder: Free web tool aiming to reduce up-front project development costs through the utilization of site survey data. Users can perform calculations on the energy demand and the required generation capacity. The tool includes financial analysis that facilitates the projection of an initial project budget.

http://www.minigridbuilder.com/

HOMER: Software for microgrid and distributed generation power system design and optimization.

http://www.homerenergy.com/

RETScreen: Clean Energy Management Software system for energy efficiency, renewable energy and cogeneration project feasibility analysis as well as ongoing energy performance analysis

http://www.nrcan.gc.ca/energy/software-tools/7465

APPENDIX 1

Technical Specifications for a Solar Mini-Grid

This appendix shows the technical specifications that were used for the stand-alone mini-grid systems under the pilot projects.

System Architecture

- Alternating current (AC) or direct current (DC) mini-grid(s): centralized or modular configuration, to serve all households within predefined village boundary

Photovoltaic Module

- Mono- or poly-crystalline silicon photovoltaic (PV) modules
- Modules to be certified to International Electrotechnical Commission (IEC) 61215 and IEC 61730 standards
- Module manufacturer to have minimum 5 years of operating history
- Minimum 20-year performance warranty at 80% of rated power
- Maximum +/– 5% power tolerances from nameplate rating
- Performance specifications shall be clearly marked on label on back of each module:
  - Rated Power in watts (W)
  - Max Power Voltage (Vmp)
  - Max Power Current (Imp)
  - Open Circuit Voltage (Voc)
  - Short Circuit Current (Isc)

Photovoltaic Array Rack (Mounting Structure)

- Constructed of corrosion-resistant metal such as aluminium, stainless steel, galvanized steel, or mild steel protected with quality primer and enamel or epoxy paint
- Fasteners made from stainless steel or hardened or treated steel for corrosion resistance
- Bolts secured with locking washers or locknuts
- Constructed on free-standing, ground mounted, or top-of-pole racks
- Accessible from ground level for cleaning and maintenance
- Designed and built to withstand at least 60 miles per hour (mph) (96.5 kilometers per hour) wind speed
- Oriented to True South and tilted between 15 and 25 degrees from horizontal

Photovoltaic Array Siting

- PV array(s) to be located in a location with less than 10% shading between 9 a.m. and 3 p.m. throughout the entire year

Photovoltaic Array Wiring

- All outdoor exposed wiring to be protected from ultraviolet (UV) radiation and physical damage.
- Outdoor wiring will have UV-resistant insulation or be protected by UV resistant plastic or metal conduit.
- PV array to battery circuit(s) should be sized for maximum 3% voltage drop at rated array power (Imp).

Photovoltaic Charge Controllers

- Maximum power point tracking (MPPT) or pulse width modulated (PWM) type
- PV charging efficiency at least 90%
- Rated current at 50 degrees Celsius must be at minimum 120% of peak array current (Isc)
- Controller must utilize passive cooling (not fans)
- Controllers to be certified to meet at least one of the following standards:
  - CE or UL 1741 Marking, IEC 62509, or IEC 62093.

System Housing

- Weatherproof steel or aluminum enclosure(s) to house batteries, power electronics, and balance-of-system components, or centralized “powerhouse”.
- Outdoor rated metal enclosures shall be white, light grey, or other high-albedo color and situated in a shaded location to minimize heat buildup from sun exposure
- Screened ventilation holes should be provided.
- For centralized systems or modular systems serving over 20 households, a masonry “powerhouse” structure with metallic roofing may be constructed instead of metal enclosures.
- System housing enclosure or powerhouse shall be rugged, secure, and lockable.
- System housing must have adequate clearance space for working access to all components and passive cooling of electronics.
- Metering display panels shall be easily viewable and all switches and/or buttons accessible.
- Protection against flooding and water, especially during rainy season.

Distribution Network

- Single- or three-phase AC (230 volt [V], 50 hertz [Hz]) or DC power distribution lines of appropriate scale to connect all planned consumers; including wooden poles securely installed in compacted sand and gravel or concrete foundations
- Conductors (wires and cables) to have appropriately rated UV sunlight-resistant insulation for main lines and exterior wiring to each household connection

- Distribution feeder circuit designs, including number of connected households on each line and conductor sizes, to have less than 5% voltage drop on any one circuit at peak combined household design load current
- Protective fuses or circuit breakers sized and located to provide adequate overcurrent protection for every distribution feeder and connected branch circuit
- Appropriate strain relief fittings, insulators, and terminals to minimize slack and the potential for physical damage to distribution wiring

Streetlights

- Pole-mounted lamps designed for outdoor installation, protected from rain and weather
- LED lamps with minimum luminous flux of 800 lumens per pole
- Timer controlled operation for a minimum of 6 hours every night; a timer control system that can turn lights on or off at specific hours of the day required for controlled operation
- Lamp to be mounted between 3.5 and 5 meters above ground level
- One streetlight per 10 houses, evenly distributed geographically throughout the village
- Grid-independent solar PV streetlights (with integrated PV panel, controller and battery) may be offered instead of connecting streetlights to solar PV mini-grid. Independent PV lighting systems must meet performance and technical specifications described above. The vendor is responsible for ensuring operation of all streetlights for 3 years starting from the date of system commissioning. Batteries to be replaced by the vendor as required for operation of all lights. At the end of the 3-year service guarantee period, the vendor should provide replacement batteries for all independent PV lights.

Consumer Lamps

- LED lamps with fixtures (overhead mounting base) to provide at least 400 lumens of illumination each
- Color temperature between 3000 Kelvin (K) and 6500 K
- Wall-mounted switches for each installed lamp

Consumer Power Sockets

- For AC systems, consumers to be provided with combined European Union–American style 230 V AC receptacles (sockets); one per household for basic service, additional as desired and purchased by consumers.
- For DC systems, consumers to be provided with 12 V "cigar lighter" style DC receptacle and a 5 V USB.

Prepayment Meters

- Prepayment energy meters with accounting software and control system
- Tamperproof or tamper-evident construction
- Maximum metering power resolution (sensitivity): 1 W
- Self-consumption < 2 W

- Non-volatile metering data (minimal loss of data with power failure)
- Prepayment meters to accommodate progressive block-rate tariffs (increasing tariffs for increasing consumption) or allow for variable pricing
- Do not require GSM (mobile data) connection for operation and/or data logging

Power Limiters (may be included as feature of prepaid meters)

- Electronic current limiting devices with automatic reset after time delay
- Power limits may be adjustable (by administrators only) with minimum service level of 30 W and maximum of 200 W
- Tamperproof or tamper-evident construction

Inverters (if required)

- Single- or three-phase inverters with continuous power output rating equal to at least 130% of expected continuous average power demand of 50 W per household at 50 degrees Celsius
- 230 V at 50 Hz
- Sealed from dust ingress and passive cooled (no fans)
- Inverters to be certified to meet at least one of the following standards:
  - CE or UL 1741 Marking, IEC 62109

Control Panel(s)

- DC rated circuit protection and disconnects (fast acting fuses and switches, or circuit breakers) for all battery connected circuits
- AC rated circuit protection for inverter output circuits
- Digital display including battery voltage, PV charging current (power), and load current (power output to consumers) (this display function may alternately be located on the controller)

Data Logging and Reporting

- Battery voltage to be observed and recorded at least hourly with automated data-logging equipment using local digital storage media (SD card or similar) and capability to upload to the internet via cell-phone carrier or other means. Connection to internet for data upload must occur at least once per month to transfer all of the data for the previous month. More frequent upload intervals are preferred.
- Household-level consumption data including average daily watt-hour consumption and peak power demand (watts or amps) to be measured and recorded for inclusion in monthly reporting described below.
- Service interruption events (power failures) to be logged (either automatically or manually) and reported monthly.
- Daily PV array charging energy (watt-Hours or DC amp-hours per day) to be metered and recorded for inclusion in monthly reporting described below.
- All recorded data to be compiled into Excel worksheet or CSV table format for monthly reporting to Nexant for 1 year after commissioning, and to its designated representative for the following 2 years.

Battery

- Sealed valve-regulated lead-acid (VRLA; absorbent glass mat [AGM], gel, or tubular) or lithium battery arrays with C/20 rated capacity for at least 2 days autonomy at design daily energy load
- Deep cycle batteries rated for at least 1,000 cycles at 50% depth of discharge (DOD)
- Reliable performance at high operating temperatures of up to 50 degrees Celsius
- Maximum of three parallel strings of cells in series. For large batteries, this will likely require use of 2 V or 6 V cells.
- Wires connected to batteries to utilize appropriately sized lugs or terminals and proper hardware

Earth Grounding System

- A grounding (earth) electrode (rod, plate, or metal pipe) shall be installed at the location of PV arrays and power electronics. All metallic parts of PV arrays, power centers, and system housings should be bonded together and connected to the grounding electrode of minimum 1-meter length and 4-square-millimeter (mm^2) cross-sectional area.

APPENDIX 2

Basics of Energy and Power

What is the difference between power and energy?

Energy is defined as the ability to do work. It refers to the amount of work a physical system can perform, or amount of energy stored, consumed, or delivered. Energy has many forms, such as kinetic, mechanical, or electrical energy.

The basic unit of energy is Joule (J), often expressed in multiples such as kilojoule (kJ) or megajoule (MJ). For example, 1 liter of diesel contains 36.3 million J, or 36.3 MJ. Other common units to indicate energy amounts include kilowatt-hour (kWh), British thermal unit (BTU), and ton of oil equivalent (toe).

Power is defined as the rate at which energy is converted or transmitted. The basic unit of power is watt (W, Joule per second), also expressed in multiples such as kilowatt (kW) or megawatt (MW).

For any given energy system, the relation between energy and power can be expressed as:

$$\text{Energy} = \text{Power} \times \text{Time (J = Ws)} \qquad \text{or} \qquad \text{Power} = \text{Energy/Time (W = J/s)}$$

For example: a 5 W light bulb in 1 hour consumes 5 × 3,600 seconds = 18 kilojoule (equivalent to 5 Wh).

Common units for energy and power are listed in the table below.

Table A2.1: Common Energy and Power Units

Energy Units	
Joule	1
Calorie	4.2
BTU	1,055
Wh	3,600
kWh	3.6×10^6
TOE	41.9×10^9

Power Units	
Watt	1
Hp	746
kW	1,000
MW	1,000,000

BTU = British thermal unit, Hp = horsepower, kWh = kilowatt-hour, MW = megawatt, TOE = ton of oil equivalent, Wh = watt-hour.

Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

Energy Conversion

When one form of energy is converted into another, not all the energy ends up where you would like it, and energy is wasted or lost to the process, usually in the form of heat. For example, light bulbs and engines give off a certain amount of heat. The ratio of the useful energy output to the required input is the efficiency of the process; the higher the efficiency, the less energy is "lost." Efficiency is usually expressed as a percentage.

The efficiency of an energy conversion process is never 100%. It can be as high as 90% (e.g., in a well-run water turbine) or a lot less (e.g., 10%–20% in an old internal combustion engine). Inefficiency can be reduced by good equipment design and use, but some is inherent to the nature of energy conversion.

What is the difference between kW and kWh?

Kilowatt (kW) is a unit of power, while kilowatt-hour (kWh) is a unit of energy.

Although they are closely related, kW and kWh are very distinct units. They should not be mixed up, although this is commonly done, even by people working in the energy sector.

There is no such thing as kW per hour, kW/h, kW per second, or kW/s.

How much electricity can a 1 MW power plant generate per year?

In theory, the maximum output in 1 year from a 1 kW power plant would be:

$$1 \text{ kW} \times 8{,}760 \text{ hours} = 8{,}760 \text{ kWh} \qquad \text{(1 year has 8,760 hours)}$$

In practice, this will be much lower because of a variety of factors, such as the technology, efficiency, operational procedures, maintenance needs, as well as the fuel or natural resources driving the plant.

The ratio of a plant's actual output to its maximum theoretical output is called capacity factor (also called plant factor or load factor). For example:

- A 10-kilowatt power plant generates 64,639 kWh in 1 year.
- This means that the capacity factor is 64,639 / (10 × 8,760) = 73.8%.

What are typical capacity factors for renewable energy technologies?

Capacity factors vary widely for different technologies. Table A2.2 shows typical values for each type.

Table A2.2: Typical Capacity Factors for Renewable Energy

Renewable Energy Type	Capacity Factor (%)
Biomass	40–80
Hydro	30–95
Solar photovoltaic	15–25

Source: ADB Myanmar Off-Grid Renewable Energy Demonstration Project Team (2017).

Developing Renewable Energy Mini-Grids in Myanmar
A Guidebook

This guidebook documents the experiences and lessons learned from developing 12 pilot mini-grid systems for off-grid energy access in Myanmar. Unelectrified rural communities typically located 10 kilometers from the national grid and without prospects of being connected to the grid in the next 5 to 10 years have been chosen for the project. This guidebook shares training materials and knowledge on the major aspects of mini-grid development for rural electrification. Further, it highlights the importance of community participation and discusses the main renewable energy technologies that are suitable for mini-grid development in Myanmar including solar, hydro, and biomass. This guidebook is intended to serve government officials, renewable energy developers, and potential investors in the development of mini-grid projects in Myanmar.

About the Asian Development Bank

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Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

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