Chapter 5

Potential of Mini-Grids and Barriers to Development

Sustainable Development Goal 7 recognises energy access as an urgent problem that needs a solution. Thus, Myanmar's government plans to reach 100% electrification by 2030. To achieve this ambitious target, both centralised (main-grid extensions) and decentralised approaches should be considered.

This chapter focuses on distributed mini-grids as an electrification option in rural areas and analyses barriers to the deployment of mini-grids in Myanmar. It presents a techno-economic analysis of renewable-based mini-grids by calculating the levelised cost of electricity (LCOE) and considering future cost reductions. Results show that solar PV and batteries are cost-competitive in off-grid areas compared to diesel, since diesel fuel prices in those areas are much higher than in urban areas.

Recent literature on the barriers to renewable energy in developing countries is also reviewed. These barriers are then looked into in the context of the renewable energy-based mini-grids in Myanmar.

Findings here have been discussed with stakeholders in Myanmar, such as those from international organisations, private companies, nongovernmental organisations, and research organisations.

5.1 Introduction

Energy access is recognised as an urgent issue that needs a solution, both globally and in Myanmar. Goal 7 of the 2015 United Nations Sustainable Development Goals calls on nations to 'ensure access to affordable, reliable, sustainable, and modern energy for all.' Although the global population without access to modern energy has decreased from 1.7 billion in 2000, 1.1 billion people still have no access (IEA, 2017a).

In Myanmar too, the main grid electrification rate is in the low 30% range. In line with Goal 7, Myanmar is thus pursuing universal electricity access by 2030.

To accelerate rural electrification, Myanmar should look at all possible solutions: main-grid extension, solar home systems (SHSs), and mini-grids. Mini-grids have received attention as a way to fill the gap between a main grid and personal/household use equipment such as solar lanterns and SHSs (IEA, 2017a; Schnitzer et al., 2014; BNEF, 2017a). Mini-grids can be used not only for lighting and mobile charging but also for entertainment purposes, such as television sets and DVD players, as well as productive uses (Schnitzer et al., 2014). Moreover, they can provide electricity to social welfare facilities, such as hospitals and schools.

Currently, mini-grids are dominated by diesel while renewables play a minor role. Mini-grids are powered by diesel in 13,000 villages, by micro-hydropower in 2,400 villages, by biomass gasifiers in 1,200 villages, and by solar PVs in 150 villages (Greacen, 2017a). While the government has been promoting renewable-based mini-grids in the World Bank-funded ‘60/20/20’ under the National Electrification Programme since 2016, the scale has been limited: eight projects in the first year and 74 proposals in the second year.

One of the barriers to the wide diffusion of mini-grids is the lack of a detailed understanding on both the financial and non-financial aspects of renewable-based mini-grids. For instance, there are not many studies about renewable energy in Myanmar. In one of the studies, ACE (2016) reported the LCOE values for renewable energy types (including solar PVs, biomass, and hydropower) for Indonesia, Lao PDR, Malaysia, Thailand, Viet Nam, and Myanmar. Out of 64 renewable energy projects assessed, only two (which are hydropower based) were in Myanmar. No solar PV project in Myanmar was included.

Another study is the Sustainable Engineering Lab (2014), which estimated the total investment for electrification using both grid extensions and off-grid programmes. The authors, however, assumed only diesel-powered mini-grids and SHSs for off-grid electrification and did not analyse renewable-based mini-grids.

Some studies reported that mini-grids powered by renewable energy, especially solar PVs, are expensive. Using Hybrid Optimization of Multiple Energy Resources (HOMER) software, the software for optimising design of microgrid, Sasaki et al. (2015) estimated the cost for rural electrification via mini-grids based on assumed load projections. They assumed three types of mini-grids powered by (i) a combination of solar PVs and biomass; (ii) micro-hydropower; and (iii) diesel generators. Win et al. (2017) compared diesel generators and a hybrid system that was composed of solar PVs, batteries, and a diesel generator. Kim and Jung (2018) compared different energy sources: diesel generators, solar PVs, lead-acid batteries, lithium ion batteries, and various combinations of these.

These studies are valuable but there remain important knowledge gaps. For example, how do rapidly improving technologies affect economic assessments?

The studies reviewed above considered the technology progress of solar PV (e.g., BNEF, 2017b) but not energy storage. Lithium ion batteries (LIB) are experiencing fast cost reductions similar to PVs (Kittner, Lill, and Kammen, 2017; Kittner, Gheewala, and Kammen, 2016; Schmidt et al., 2017; IRENA, 2016). Since LIBs have better characteristics (e.g., a long life cycle in deeper discharge usage with higher round-trip efficiency) than lead-acid batteries (IRENA, 2017), using LIBs instead of lead-acid batteries could change the economics of solar-based mini-grids. In fact, developers in Myanmar are considering LIBs for their mini-grids in the near future.

In implementing mini-grid policies, non-techno-economic considerations are crucial, too. Greacen (2017b) conducted a SWOT analysis on mini-grids in Myanmar and identified various issues related to mini-grid development. On the other hand, there is a literature that systematically explored the barriers to mini-grid development in other countries (Comello, Reichelstein, Sahoo, and Schmidt, 2017). A more in-depth analysis on what hampers mini-grid development specifically in Myanmar would be helpful to both policymakers and stakeholders.

5.2 Assessment of Economic Viability of Mini-grids in Myanmar[3]

This section analyses the economic viability of mini-grids in Myanmar. Mini-grid LCOE values are calculated not only for diesel generators and/or solar PVs with lead-acid batteries, but also for configurations with LIBs based on their projected costs.

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[3] This section is mainly based on a paper published in the ERIA discussion paper series.

5.2.1 Methodology and Data

The methodology broadly follows Blum et al. (2013), who examined the LCOE of mini-grids in Indonesia. Cost estimates and the load assumption are based on three field surveys in February, March, and October 2017 and on existing literature. Interviews of developers were carried out at Yangon Technological University. Questionnaires and follow-up were done in collaboration with the Mitasu Consultants Group in Yangon. To protect anonymity of the survey respondents, only the averaged cost data were used.

5.2.2 LCOE Calculation

Levelised costs of electricity for different mini-grid power sources were calculated using a formula presented in many publications (e.g., IEA and NEA, 2015):

$$\mathrm{LCOE} = \frac{sum\ of\ costs\ over\ lifetime}{sum\ of\ electrical\ energy\ produced\ over\ lifetime} = \frac{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+r)^t}}$$

where

E_t is the energy produced in year t,

C_t are the costs in year t,

C_0 are the capital costs, and E_0 is 0.

The calculation of the LCOE for solar PVs combined with batteries followed that described by Pawel (2014). The denominator of the LCOE formula represents, if multiplied by the LCOE itself, the net present value of electricity in the project period. The amount of sold electricity [kWh] is used for the denominator, assuming that it equals the load and that generation of electricity always covers the load. The amount of produced electricity is not used because there would obviously be a loss of electricity not consumed or charged to batteries during daytime.

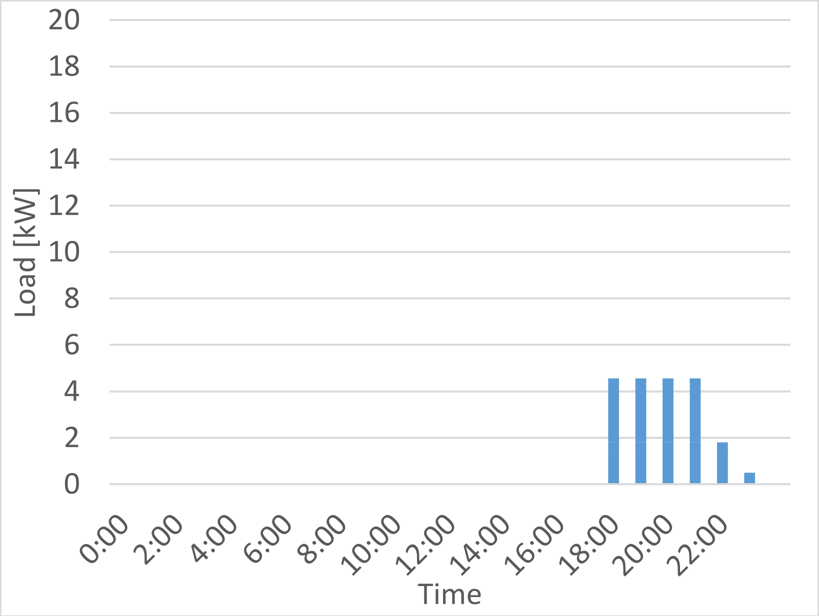
5.2.3 Load Assumption

Two load scenarios are assumed. Because not enough power consumption data for off-grid areas are available, the study's assumption was based on cumulative power consumption of appliances as provided by households in a survey done by one of the solar PV mini-grid developers. The number of households per village was assumed to be 100, which is similar to the typical number of households for interviewees' mini-grids.

Scenario A is a lower load case for basic usage, such as light-emitting diode (LED) lights and TVs. The assumptions were that each household has three LED lights – two indoors and one outdoors – and three out of four households have a TV. The assumed night-time load was 20.5 kWh/day, as shown in Figure 5-1.

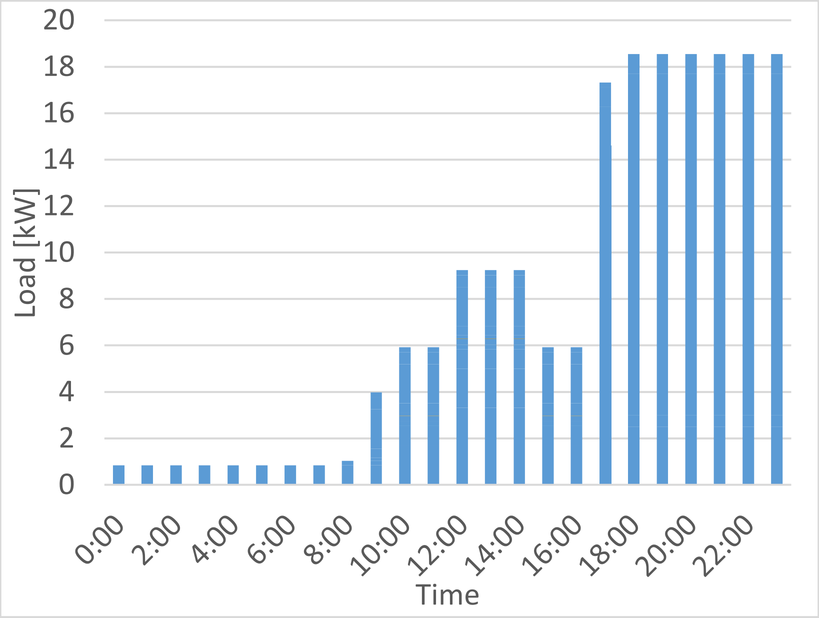
Scenario B is a higher load case representing both household use at night and productive use during the daytime. 'Household use' was assumed to refer to appliances that households wish to have in the future, based on a feasibility study done by one of the developers. 'Productive use' was assumed to refer to the total number of small businesses that the developers stated were in their mini-grids. Each load from productive use was taken from the literature (Blum et al., 2013; Aye, 2015). The assumed load was 192 kWh/day, which comprised 61 kWh from 06:00 to 18:00 and 131 kWh from 18:00 to 06:00; this profile is shown in Figure 5-2. The detailed load assumptions are outlined in Appendix 3.

Figure 5-1. Load A: Night Only



Source: Authors.

Figure 5-2. Load B: Day and Night



Source: Authors.

5.2.4 Cases for Calculation

The following system configurations are assumed.

For power sources, diesel and solar PVs are compared. Solar PVs need some kind of backup because the systems are isolated from the main grid. Two types of backups were assumed: batteries only; and a combination of batteries and diesel generators.

- Power source
  - Diesel: conventional diesel generator
  - PV + Battery: solar PVs backed up by batteries
  - PV + Battery + Diesel: hybrid systems of solar PVs backed up by batteries and a diesel generator

As explained above, fuel prices differ greatly in each area. One of the interviewees explained that the price around their site was about MMK2,000/L (about US$1.46/L) when it was MMK750/L (about US$0.55/L) in Yangon. Two fuel prices are assumed: one to cover a relatively low cost area and the other, the highest priced area.

- Fuel price (FP)
    - International price for diesel fuel costs
    - International price multiplied by 2.7 (= 2,000/750), representing the ratio between urban and off-grid rural areas

For batteries, the current dominant technology is valve-regulated lead-acid batteries; however, lithium ion batteries are expected to be replaced in the near future. Once LIBs come into use because of their reduced cost, the cost of solar PVs is also expected to drop below their current price. Therefore, the current cost scenario assumes that lead-acid batteries are used while the future cost scenario assumes LIB technology.

- Equipment costs
    - Current cost (lead-acid batteries): average price for PVs and lead-acid batteries based on this study's surveys
    - Future cost (LIBs): PV costs decreased to 'Sunshot 2020'[4] target prices at the residential scale (Woodhouse et al., 2016) and costs of LIBs decreased to US$124.24/kWh in 2020, as forecasted by Kittner et al. (2017)

Based on the assumptions above, 12 cases for calculation are established. Table 5-1 summarises each case and its capacity. Each capacity was set to cover loads and will be explained in detail in sections 5.2.5, 5.2.6, and 5.2.7.

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[4] Sunshot is an initiative of the US Department of Energy. It sets goals and cost targets. For more information, please refer to, e.g. 'The SunShot Initiative – Department of Energy', https://www.energy.gov/eere/solar/sunshot-initiative

Table 5-1. Scenarios and Their Capacities

		Capacity for load A: Night Only	Capacity for load B: Day and Night
Diesel	**FP × 1**	(1a) Diesel 5 kVA	(1b) Diesel 20 kVA
	FP × 2.7	(2a) Diesel 5 kVA	(2b) Diesel 20 kVA
PV + Battery	**Current Lead-acid batteries**	(3a) PV 7.9 kW Battery 39.5 kWh	(3b) PV 81.1 kW Battery 252.5 kWh
	Future LIBs	(4a) PV 7.4 kW Battery 22.5 kWh	(4b) PV 76.9 kW Battery 143.5 kWh
PV + Battery + Diesel	**FP × 1**	(5a) PV 3.9 kW Battery 23.0 kWh Diesel 3.9 kVA	(5b) PV 33.5 kW Battery 91.6 kWh Diesel 33.5 kVA
	FP × 2.7	(6a) PV 3.9 kW Battery 23.0 kWh Diesel 3.9 kVA	(6b) PV 33.5 kW Battery 91.6 kWh Diesel 33.5 kVA

PV = photovoltaic; FP = fuel price.

Source: Authors.

Table 5-2 lists the common assumptions for the calculations.

Table 5-2. General Assumptions for Calculations

	Value	Source
Discount rate	10%	ACE, 2016
Project term	20 years	Our assumption
Number of households in a village	100	Simplified number based on survey
Loss of distribution	4%	Blum et al., 2013

Source: Authors.

5.2.5 Mini-grids Powered by Diesel Generators

As explained above, two diesel fuel price cases are assumed: (i) the international fuel price (FP × 1), which represents urban areas; and (ii) the international fuel price multiplied by 2.7[5] (FP × 2.7) for rural areas. The international fuel price is based on forecasts by the US EIA (2015).¥

Table 5-3 lists the assumptions for a mini-grid powered by a diesel generator. We assumed the diesel generator could follow the load and adjust its output.

Table 5-3. Assumptions for Diesel-powered Mini-grids

	Value	**Source**
Efficiency	26%	Blum et al., 2013
Operating hours	(Load: night only) 6 hours/day (Load: day & night) 24 hours/day	Survey by the authors
Capital expenditure (CAPEX)		
cost of equipment	US$259/kW	Survey by the authors
cost of engineering	US$241/kW	Lazard, 2014
Operation & Maintenance cost	US$0.026 /kWh	Dobermann, 2016
Replacement	None	Lifetime: 20 years (IRENA and ACE, 2016)

kWh = kilowatt-hour.
Source: Authors.

5.2.6 Mini-grids Powered by Solar PVs with Batteries

In this study, crystalline polysilicon is chosen as the PV solar technology because it is the dominant technology in small-scale residential applications. Isolated solar PV mini-grids need storage to accommodate the load at night. The current dominant storage technology is lead-acid batteries but is slowly being replaced by LIBs.

Because the cost of solar PVs and LIBs is assumed to continue to move downwards, two cost cases are set in this study. The current cost case assumes the use of lead-acid batteries, and

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[5] = 2000/750.

prices are averages based on the study’s surveys. For specifications, the highest class of lead-acid batteries is assumed to be installed in Myanmar. Also, current installation costs for solar PV systems is assumed to be US$2,178/kW, which is based on the average results from the interviews. This is similar to the price in ASEAN countries, which is US$2,576/kW, as reported by the ACE (2016). The assumptions are summarised in Mini-grid Powered by the Combination of a Solar PV System with Batteries and a Diesel Generator

A hybrid system consisting of solar PVs, batteries, and a diesel generator has been installed in many sites in Myanmar. The capacities of solar and diesel systems differ from site to site; thus, it is assumed here that the capacity of each is the same, following the configuration of Blum et al. (2013). The load during the daytime is covered by solar PVs, and excess generation is used to charge the batteries. At night, diesel powers the first three hours while the batteries are discharged for the rest of night. The capacities are shown in Table 5-1. The batteries are assumed to be made of lead acid; other assumptions are aligned with those of the current costs in Table 5-4.

Table 5-4We assumed the initial cost of batteries to be US$286/kWh, referring to the actual price, which was close to the interview results.

Meanwhile, the future cost case assumes that LIBs will be used and that their price will decrease to US$124.24/kWh in 2020, as estimated by Kittner et al. (2017); and PV costs will decrease to the ‘Sunshot 2020’ target prices at the residential scale (Woodhouse et al., 2016).

5.2.7 Mini-grid Powered by the Combination of a Solar PV System with Batteries and a Diesel Generator

A hybrid system consisting of solar PVs, batteries, and a diesel generator has been installed in many sites in Myanmar. The capacities of solar and diesel systems differ from site to site; thus, it is assumed here that the capacity of each is the same, following the configuration of Blum et al. (2013). The load during the daytime is covered by solar PVs, and excess generation is used to charge the batteries. At night, diesel powers the first three hours while the batteries are discharged for the rest of night. The capacities are shown in Table 5-1. The batteries are

assumed to be made of lead acid; other assumptions are aligned with those of the current costs in Table 5-4.

Table 5-4. Assumptions for Solar PVs and Batteries

Specifications	Current Cost	Future Cost
PVs	crystalline polysilicon	
Capacity factor	18%* (World Bank & ESMAP, 2017)	
Degradation rate	1% (Authors' assumption)	0.2% (Woodhouse et al., 2016)
CAPEX (Capital expenditure)	US$2,707/kW (average number from survey by the authors)	US$1,600 /kW (Woodhouse et al., 2016)
Operation & Maintenance cost	1% of CAPEX (ACE, 2016) With inverter replacement	US$10/kW without inverter replacement; inverter lifetime is assumed to be 30 years
Batteries	**Lead-acid batteries (current price)**	**LIBs (forecasted price)**
Round-trip efficiency	90% (HOPPECKE Batterien GmbH & Co. KG, 2016)	95% (IRENA, 2017)
Depth of discharge**	60% (HOPPECKE Batterien GmbH & Co. KG, 2016)	100% (IRENA, 2017)
Capital Expenditures (CAPEX)	US$286***/kWh (Off-Grid Europe Gmbh, 2017)	US$124.24♐/kWh (Kittner et al., 2017)
Operation & Maintenance cost	US$0 /kW (Lazard, 2017)	US$0.04/kWh (Lazard, 2017)
Replacement♐♐	Every 7 years	Only in the 11th year

ESMAP = Energy Sector Management Assistance Program; PV = photovoltaic; LIBs = lithium ion batteries

Limitations: For simplicity, the self-discharge of the lead-acid battery and the relationship between the available capacity and discharge time were not considered.

Notes: *Calculated from 4.32kWh/kW daily in Nay Pyi Taw.

**Depth of discharge was set to minimise total costs including Capex and replacement cost within the operation range.

**Exchange rate US$/EUR 1.15880 (XE.com, 2017a)

[♐] In 2015 US$.

[♐♐] Calculated from life cycle.

5.2.8 Calculation Results

Figure 5-3 shows the LCOE calculation results for each case when the load is scenario A (night-time only) while Figure 5-4 shows the LCOE of scenario B (when the load occurs both in the day and night-time). A diesel generator may not be an affordable option in rural areas because fuel costs in such areas would be significantly higher than in urban areas. Case 2 represents the fuel cost in rural areas while case 1 is that in urban areas.

Most of the diesel LCOE is due to fuel costs; hence, the LCOE is estimated as proportional to the fuel price. Two cases of diesel prices are assumed. Meanwhile, the LCOE in other areas was roughly presumed, even though fuel prices differ by area, distance from the distribution centre, and means of transportation. In addition to these domestic conditions, the international fuel price is itself very volatile.

The LCOE of the combination of solar PVs and lead-acid batteries (represented in case 3a) is US$0.68/kWh, which is relatively expensive. When loads occur only at night, the electricity generated by solar PVs during the day needs to be stored. The system needs enough battery capacity to meet demand, whereas the capacity of solar PVs is set relatively low. Currently, battery prices are still high even for lead-acid batteries; hence, batteries need to be used more efficiently.

The LCOE of solar PV + LIB (as represented by case 4a) indicates it is the least expensive amongst the cases. The longer cycle life of LIBs means fewer replacements are required – i.e., only once in the project period in contrast to twice for the lead-acid batteries). The capital expenditure of LIB batteries occupies a smaller portion of the LCOE than in case 3a (with lead-acid batteries).

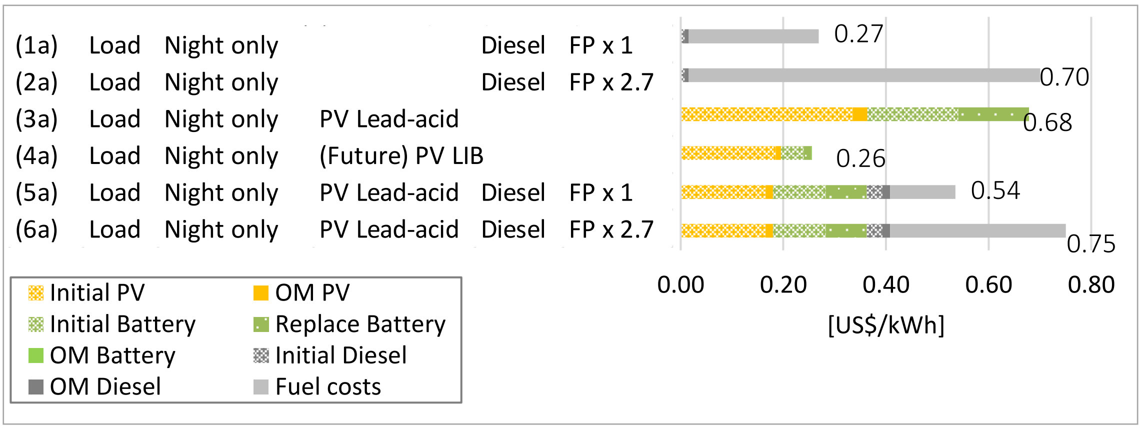
It is not necessarily appropriate to suggest that the LCOE becomes less expensive after combining solar PVs, batteries, and a diesel generator. Each component's capacity was set following the configuration of Blum et al. (2013), but the optimal combination should be further investigated. The system capacities of cases 5a and 6a, and cases 5b and 6b were the same in each load scenario, as shown in Table 5-1. Thus, the levelised costs from solar PVs and batteries were the same in cases 5a and 6a, and 5b and 6b. The differences in LCOE were the result of fuel costs.

When the load became greater and increased continuously both in the daytime and at night, the

LCOE generally became less expensive (compare Figure 5-3 with Figure 5-4). However, the differences per load scenario of the diesel power source, represented by cases 1a and 1b, and cases 2a and 2b were very small. This is because it was assumed in the study that diesel generators could adjust their output according to the load demand.

The LCOE of solar PV + lead-acid battery became less costly when there were loads during the daytime and at night, as in cases 3a and 3b. As explained above, an absence of load in the daytime requires batteries with higher capacity and lower capacity of solar PVs. Daytime loads reduce the inefficiency of the system configuration. The LCOE of solar PV + LIB in cases 4a and 4b only differed slightly because battery prices were low enough that the capacity balance between PVs and batteries did not affect LCOE as much.

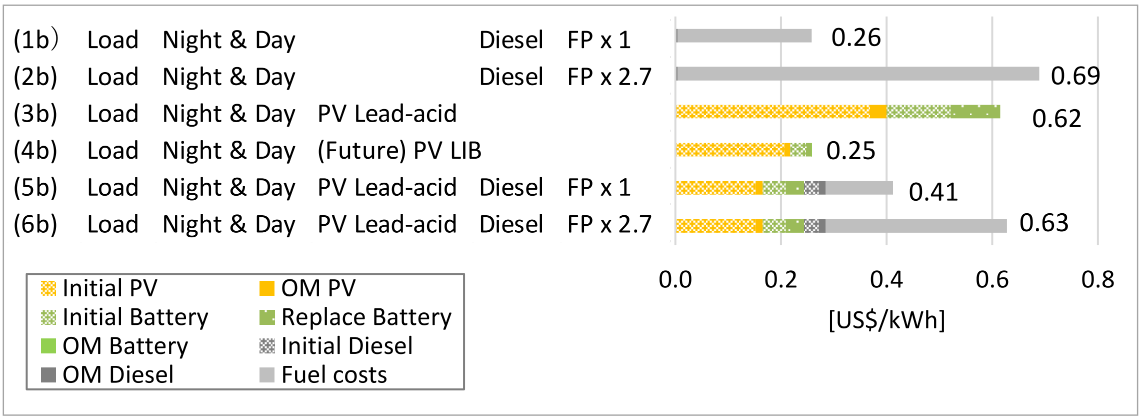
Figure 5-3. Calculation Results of LCOE: Load A (Night Only)



FP = fuel price; PV = photovoltaic; OM = operation and maintenance.

Source: Authors.

Figure 5-4. Calculation Results of LCOE: Load B (Night and Day)



FP = fuel price; PV = photovoltaic; OM = operation and maintenance.

Source: Authors.

The LCOE values of hybrid systems (i.e., systems with solar PVs, batteries, and a diesel generator) were observed to be lower when there were loads during the daytime for cases 5a and 5b and for cases 6a and 6b. Because loads in the daytime were covered by solar PVs, systems were used more effectively in cases 5b and 6b than in cases 5a and 6a. Capacities of each type of equipment (solar PVs, batteries, and diesel generators) became larger in cases 5b and 6b but the contribution of batteries to LCOE declined from 34% in case 5a to 19% in case 5b; and from 25% in case 6a to 12% in case 6b. In contrast, the proportion of fuel costs increased from 46% in case 6a to 55% in case 6b; and from 24% in case 5a to 31% in case 5b because the fuel price in case 6 was higher than that in case 5. Results were generally consistent with the findings of previous studies (Skat, 2017; Kim and Jung, 2018).

The LCOE calculation results for diesel were a little out of range, but they depended heavily on fuel prices during the project period; therefore, the differences may be due to the source of fuel prices forecasting.

The solar-based system is competitive when compared with the diesel-based ones, but how does it compare to the main grid? Figure 5-5 shows a comparison of residential tariffs on the main-grid, one of the tariffs on the hybrid system's mini-grid, and the LCOE calculation results for cases 1 to 6. The mini-grid tariff was subsidised by the government under the 60/20/20 project and became profitable for developers; it seems difficult to keep tariffs at an affordable level without subsidies. The main-grid tariff for residential customers was US$0.026 to US$0.036[6]/kWh (ADB, 2016) and was heavily subsidised. It is nearly 10 times higher than the mini-grid's tariff.

5.3 Barriers to Development of Mini-grids

The previous section revealed the economic viability of mini-grids with renewables, especially in remote rural areas with high diesel prices. However, it also showed that heavy subsidies for electricity tariffs highly distort competitiveness. There are many more possible barriers, including the threat of main grids extending further to villages where mini-grids are already operating. In the first step, a comprehensive typology of barriers would be helpful to analyse

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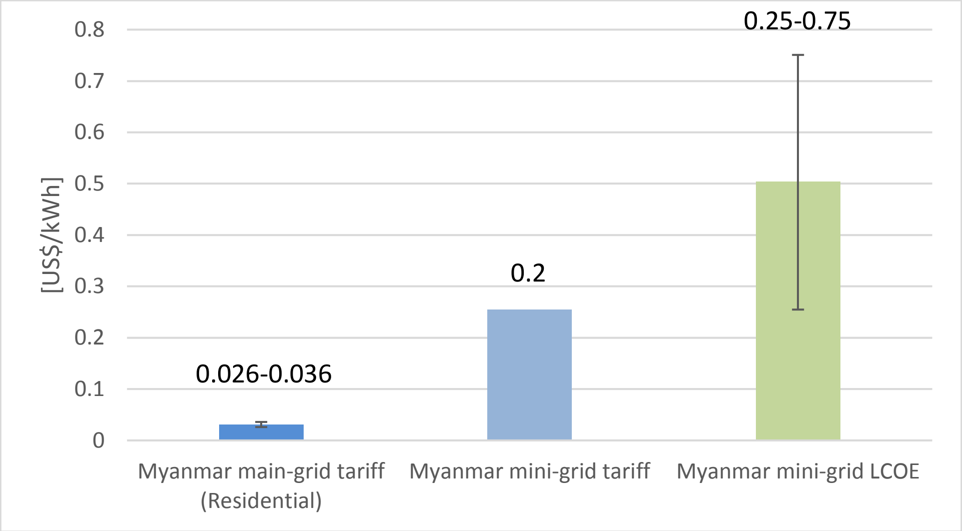
[6] 1 US$ = 1,370.71 (XE.com, 2017b)

further possible options to remove the barriers.

Figure 5-5. Comparison of Tariffs and LCOE Values



Source: ADB (2016). Modified by Authors.

5.3.1 Barrier Typology

This study drew on the barrier typologies developed by Painuly (2001) and Comello et al. (2017), and updated these based on a wide survey of literature on barriers to renewable energies in developing countries. These were further reviewed within the context of Myanmar through discussions with stakeholders in Myanmar. The meeting with stakeholders were held between 24–30 March 2018 in person and through Skype on 7–12 April 2018. Stakeholders included officers/consultants from international donor organisations, private companies, nongovernmental organisations, and local researchers. Visits to some mini-grids (one in March 2018) gave the authors insights and allowed then to discuss with locals and mini-grid operators.

Table 5-5 shows this study's updated barrier typology, including some variables unique to Myanmar (such as indigenous technologies developed during the time of the country's isolation).

Table 5-5. Barrier Typology

Category	Sub-categories	Description	Source
Financial	Access to financing	Because of the lack of familiarity with project financing through a financial institution, it is difficult to access loans. Also, immature stock and debt markets limit options for financing arrangements.	Gershenson et al. (2015); Greacen (2017b); Ahlborg and Hammar (2014); T. S. Schmidt, Blum, and Wakeling (2013); Luthra, Kumar, Garg, and Haleem (2015); UNCDF/UNDP (2012)
	High capital cost	Even if funds are arranged, financing costs are high. In the case of loans, interest rates are higher and loan fees are costly.	Painuly (2001); Greacen (2017b); Gershenson et al. (2015); Comello et al. (2017); Luthra et al. (2015) ; UNCDF/UNDP (2012)
	Insufficient capital (developer)	Because of the immature financial market, developers need to increase capital, but it is rare for them to be able to raise an ample amount.	Painuly (2001); Gershenson et al. (2015); Comello et al. (2017)
	Insufficient capital (consumer)	Customers' financing methods are also limited. Microfinance is relatively new, and unofficial money lenders are expensive.	Painuly (2001); Gershenson et al. (2015); Comello et al. (2017)
	Currency risk	If financing is not based on local currency, companies are exposed to exchange rate risks because their revenue and expenses are in different currencies.	Gershenson et al. (2015)

	Long payback period	The low rate of return means it takes longer to pay back the investment.	Painuly (2001); Comello et al. (2017) ; UNCDF/UNDP (2012)
Economic	High transaction costs	Not only the small size of projects, but also project locations make transaction costs higher.	Painuly (2001); Palit and Chaurey (2011); Gershenson et al. (2015); Ahlborg and Hammar (2014)
	Small market size	The Myanmar market has just started and is developing, although the international market has expanded rapidly.	Painuly (2001); Palit and Chaurey (2011); Bhattacharyya (2013); Luthra et al. (2015)
	Low demand	Creating demand in addition to basic use such as for lighting is still a challenge for operators.	Painuly (2001); Palit and Chaurey (2011); Bhattacharyya (2013); Ahlborg and Hammar (2014)
	Tariff structure: cost-revenue gap	The design of the tariff structure affects the business model	Bhattacharyya (2013); T. S. Schmidt et al. (2013); Comello et al. (2017); Ahlborg and Hammar (2014); Hasan (2018); Tenenbaum, Greacen, Siyambalapitiya, and Knuckles (2014)
	Customers' ability to pay	Rural villages are mainly agricultural, where incomes could be seasonal.	Bhattacharyya (2013); Palit and Chaurey (2011); Ahlborg and Hammar (2014)
	Revenue collection uncertainty	Operators need to make sure customers pay for electricity, sometimes using new technology such as Pay As You Go.	The Climate Group (2015); Franz et al. (2014); Bhattacharyya (2013); Ulsrud et al. (2011); Blum, Wakeling, and Schmidt (2013); Hasan (2018)
Social/ Cultural	Negative externalities	Existing local mini-grid businesses were nearly non-commercial but the introduction of business models	Stakeholders' interviews

	caused by international organisations	has changed the mindsets of operators and/or customers.	
	Education	The educational gap makes it difficult for local companies to obtain financing from international organisations that provide lower capital costs. The language barrier (non-English speakers) is part of the reason.	Stakeholders' interviews
	Community acceptance	Unlike personal-use equipment such as SHSs, mini-grid projects need a certain level of community acceptance for execution.	Painuly (2001); Comello et al. (2017)
	Geographical difficulty	Residential areas of minor ethnic groups overlap with the off-grid areas. Language and cultural differences make project implementation more difficult.	Stakeholders' interviews
	Perception of inferior quality	Especially in the early stages, it is difficult to offer a 24-hour, seven-days-a-week service.	Bhattacharyya (2014); Franz et al. (2014); Comello et al. (2017)
	Theft and non-technical loss, shared resource	Non-technical loss including theft, incorrect metering, and imperfect tariff collection can damage the business. Also, it is difficult to prevent	Greacen (2017b); Gershenson et al. (2015); Comello et al. (2017); Ahlborg & Hammar (2014)

		households from using more than their share without appropriate payment scheme.	
Technical	Indigenous technology	The indigenous technology may be different from the international standard in many respects but should not be flatly disallowed.	Stakeholders' interviews
	Lack of local expertise	Operators need to start training local workers for operation and maintenance.	Painuly (2001); T. S. Schmidt et al. (2013); Greacen (2017b); Comello et al. (2017); Ahlborg and Hammar (2014); Luthra et al. (2015) ; UNCDF/UNDP (2012)
	Durability and quality	Quality at installation should be supplemented by appropriate maintenance	Painuly (2001); Gershenson et al. (2015); Comello et al. (2017); Ahlborg and Hammar (2014)
	Operation and maintenance	Appropriate operation and maintenance often fail to be sustained	Gershenson et al. (2015); Comello et al. (2017); Ahlborg and Hammar (2014)
	Intermittency	The supply fluctuates over the day or season (typical for intermittent renewable energy sources).	T. S. Schmidt et al. (2013); Comello et al. (2017); Luthra et al. (2015)
	Lack of interoperability with main grid	Mini-grids can be designed without considering connections to the main-grid because of the absence of technical rules.	Comello et al. (2017)
Regulatory	Lack of regulatory framework	There are no regulations for mini-grids.	Greacen (2017b); Painuly (2001); Luthra et al. (2015)

	Institutional capacity	Institutions are tied up with their current work and it is difficult to coordinate priorities between ministries and/or other institutions.	Ahlborg and Hammar (2014); Bhattacharyya (2013); Comello et al. (2017); del Barrio Alvarez (2018); Luthra et al. (2015)
	Lack of technical standards and codes	Without technical standards or codes, it is difficult to maintain a certain level of quality for mini-grids. Also, rules for industrial waste, tar, and lead-acid should be established for sustainable development.	Painuly (2001); T. S. Schmidt et al. (2013); Comello et al. (2017) ; UNCDF/UNDP (2012)
	Threat of grid extension	Mini-grid operators do not know what will happen after the main grid reaches their customers' villages.	Bhattacharyya (2013); Kobayakawa and Kandpal (2014); The Climate Group (2015); Comello et al. (2017); Hasan (2018); Tenenbaum, Greacen, Siyambalapitiya, & Knuckles (2014)
	Lack of enforcement	Policy plans with some enforceability are needed to promote renewable energy, such as feed-in tariffs or renewable portfolio standards.	Painuly (2001); Comello et al. (2017) ; UNCDF/UNDP (2012)

LCOE = levelized cost of electricity

Source: Created by Authors.

The subsections below discuss each form of barriers to mini-grids.

5.3.2 Financial Barriers

Lack of access to financing/high capital cost/Insufficient capital (developer)/Insufficient capital (consumer)

Just like the energy sector, financial sectors in Myanmar need to be developed. Because financial institutions do not have enough experience in financing, loan financing is limited. Therefore, they are also less experienced with project financing and lack the knowledge to evaluate projects.

These situations make it difficult for developers to access financing. Even if they can arrange for loans, the terms are unattractive with short terms (e.g., one year) and high interest rates (Greacen, 2017b). As of 2017, the legal ceiling on bank loan rates is 13% per year (Gilmore and Robinson, 2017). Mini-grid projects are relatively small, so funding costs increase (Painuly, 2001; Palit and Chaurey, 2011).

Microfinance is one of the funding options. In Myanmar, loan amounts through microfinance accounted for 3% of the total loans in the country in 2016 (Ono, 2017). However, the legal ceiling on microfinance interest rates is 3.5% per month, the average interest rate is 2.5% per month, and the maximum loan amount is US$4,000 (Dave Grace and Associates, 2016). Microfinance is intended for small businesses and unsuited for the scale of mini-grid businesses. It is designed more for customers of mini-grids than for developers/operators. It should be noted that the microfinance interest rate is far below the 10% per-month rate offered by informal money lenders. In Myanmar, the interest rate is generally calculated on a simple interest basis (Takahashi, 2000).

Because of the immature financial market, developers need to increase their capital, which is rarely achieved.

Currency risk

If financing is not based on the local currency, companies will be exposed to exchange rate risks because their revenues and expenses are in different currencies. In the five years from 27 April 2013 to 26 April 2018, the currency exchange rate record low was K885/US$ (on 27 April 2013) while the record high was MMK1,381/US$ (on 22 December 2016) (XE.com, 2018). Foreign financial institution contracts are normally based on the US dollar, leaving the currency risk on the Myanmar side of the transaction.

Long payback period

Mini-grid customers are primarily in the middle- or low-income level. Because of the nature of the business, mini-grid operators do not make large profits, and the growth in demand takes time to gain some leverage. The lower rate of return means it takes longer to pay back the investment.

5.3.3 Economic Barriers

High transaction costs

Both a project's size (i.e., small) as well as the distance of its location increase transaction costs. Project sites are generally far from financial institutions (e.g., banks), which means it takes longer and costs more for the lender to conduct due diligence on projects.

Small market size

The use of renewable energies, especially solar PV and wind, are increasing rapidly worldwide. Mini-grids are also becoming more widespread. However, the Myanmar market has just been established and is still developing. Multinational companies in the mini-grid business are also expanding but rarely enter the Myanmar market.

Low demand

Creating demand for more-than-basic uses beyond lighting is still a challenge for operators. It is difficult to find long-term data on electrification in off-grid villages.

In villages with main grids, in contrast, it did not take long before television sets, videos players, refrigerators, rice cookers, and cooking stoves came into use soon after electrification. When the village began to have access to electricity in 1994, 18 out of 156 households installed meters, which connected them to the main grid. Five households owned televisions, one owned a video player, and two owned refrigerators. The resident who owned the video player earned by showing videos to villagers. One villager who owned a refrigerator made ice candies and sold them to children on their way home from school. Thus, during the main grid's early phase, electrical appliances could be considered as capital goods rather than durable consumer goods (Takahashi, 2018).

Unlike the main grid, mini-grid businesses need enough consumer demand that can pay for the energy generation of the area. Telecom towers are a good example of anchor customers of mini-grids; however, telecom towers are not often near an off-grid village. Because the main industry in rural areas is agriculture, agricultural machinery (e.g., power tillers, cultivating roller boats, threshers, combine harvesters, and transplants [Swe Mon Aung, 2018]) can be an important source of demand once the village is electrified.

Tariff structure: cost-revenue gap/Customers' ability to pay

There is no one-size-fits-all tariff structure (Tenenbaum et al., 2014). There are many factors to consider when designing tariffs: e.g., the energy [kWh] base or power [kW] base, type of plan (prepaid or post-paid), and number of lights or other appliances. In addition to these, customers are normally classified as industrial or residential, with payment exemptions for poor households.

Tariff designs affect the revenue collection. Prepaid cards are the dominant payment system for current Myanmar mini-grids but there have not been any regulations for mini-grid tariffs. This situation is related to regulatory barriers, which will be discussed later in this chapter. In the absence of a legal basis, operators are exposed to the risk of pressure to reduce tariffs because mini-grid tariffs are set by mini-grid operators.

Also, tariffs are set to the level where customers are able to pay, but there often is a gap between cost and revenue; grants are needed to cover some costs such as capital expenditure.

Since the main industry in rural villages is agriculture, customers' incomes could be seasonal. There is not enough variety in their sources of livelihood to spread their income through the off-season. Operators need to consider the industrial structure of villages and the residents' income seasonality.

Revenue collection uncertainty

Uncertain in revenue collection is related to the previous barrier: Companies need to be able to maintain their revenue collection rate. The technology known as Pay as You Go is one of the prepaid methods. As soon as customers pay the tariffs, operators unlock their access so that the former can then use the electricity. Pay as You Go enables operators to reduce the costs of bill collection and prevent free riders.

5.3.4 Social/Cultural Barriers

Negative externalities caused by international organisations

During Myanmar's isolation from the international community under a military government and socialist system, mini-grids in Myanmar had developed independently of the international business ecosystem (Vaghela, 2017b; Vaghela, 2017a). Existing local renewable energy-based mini-grids were powered by micro hydropower or biomass gasifiers using rice husks. These occurred in the informal sector and were not covered by government statistics.

One of the stakeholders explained the business model and situation to this study's authors. A community – mostly a village – invested in a mini-grid, which was operated by one family that employed their own household members. After saving enough money for the equipment, they expanded their generation capacity and/or grid. Their business was initially social and nearly non-commercial, until a business model was introduced to the operators and/or customers.

Under the initial business model, target returns were very low or sometimes zero, and operators handled their customers without the help of any sophisticated accounting reports.

Knowing that solar PV mini-grids were funded by the government and international organisations, customers began to acknowledge the mini-grid as a commercial business and turned skeptical regarding the profit operators were making off them. In spite of the presence or absence of commerciality, the relationship changed, and trust was lost.

Schmidt et al. (2013) pointed out that aid from international organisations distorted the market, and while the higher salaries paid by international organisations attracted capable human resources, this led to a lack of human resource within local governments. These points were not raised during the discussion with stakeholders in Myanmar; however, one of the stakeholders did quietly lament the financial aid scheme, noting that because subsidies often distort markets, these should be designed more carefully and that soft loans are preferable.

Educational gap

Relatively new solar PV companies in Myanmar have either highly educated leaders or employees who are capable of drafting quality proposals that withstand screening at the international level. In contrast, the long-established mini-grids of micro-hydropower or biomass gasifiers were, as previously noted, mostly household industries and, according to one stakeholder's stories, are ran by individuals who have yet to learn how to work with something as simple as Microsoft Excel. Such educational gap makes it difficult for small, local companies to obtain financing from international organisations, which they hope could finance their capital costs.

The language barrier is part of the problem. There are 135 ethnic groups in Myanmar[7], with some locals unable to speak Burmese.

Government officers can certainly speak Burmese and can communicate, but speaking in English to officers from international organisations could have made it easier to pitch proposals for acceptance.

Community acceptance

Unlike personal use equipment such as SHSs, a mini-grid project needs a certain level of community acceptance for execution. A village electrification committee is often organised for this purpose.

Geographical difficulty

Residential territories of minor ethnic groups overlap the off-grid areas. Language and cultural differences make projects more difficult in those area, as pointed out by Del Barrio Alvarez (2018).

Perception of inferior quality

Particularly during the early stages of a mini-grid's operation, it is difficult to supply energy 24 hours a day, seven days a week. Neither can the main grid offer such capability. However, it is important to get community acceptance of inferior quality in advance as it will reduce customer dissatisfaction for the supply shortage. It will be easier for people to accept inferior quality if they know the main grid quality is bad as well or even worse than the minigrid in advance.

Theft, non-technical loss, and 'shared resources'

It is difficult to prevent theft completely, in rural area as well as in urban area. Non-technical

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[7] As the definition of ethnic groups in Myanmar and non-Burmese speaking groups are outside the scope of the study, these are not discuss in this paper.

losses, which are not only a result of theft but also incorrect metering, and imperfect tariff collection can occur too. Also, the consumers of renewable-based minigrids share the limited resources. It is difficult to stop one family from using more than their allocated share. However, the risk of shared resource can be reduced with adopting appropriate payment schemes.

5.3.5 Technical Barriers

Indigenous technology

As mentioned earlier, there were indigenous types of mini-grids as well as equipment technology (e.g., hydro turbine) developed organically in Myanmar. Their designs might differ from international versions, but this should not mean indigenous technology should be disallowed.

Lack of local expertise/Durability and quality/Operation and maintenance

Because off-grid villages have not been electrified, these areas do not have any available electrical engineers. Thus, operators need to start training local workers for local employment. Capacitating local resources helps improve and sustain the durability and quality of infrastructure during installation as well as maintenance.

Intermittency

Generation of renewable energy sources in mini-grids is intermittent. For example, solar resources vary daily and seasonally; water volume for hydropower fluctuates seasonally; and biomass using rice husks is affected by the harvest season.

Lack of interoperability with main grid

In Myanmar, there are no rules or codes covering mini-grids. Mini-grids can be designed without considering how they relate to the main grid. If there is sudden decision to extend the main grid’s coverage area, investment in standalone mini-grids already existing in the overlapping coverage area is wasted or becomes redundant.

5.3.6 Regulatory Barriers

Lack of regulatory framework

No regulations cover mini-grids at this moment. However, donor organisations and government are currently working on a draft regulation.

Institutional capacity

After ministries underwent structural changes in 2016, the energy sector is now under the jurisdiction of the MOEE. However, the authority over various energy sources is complicated. Off-grid electrification is under DRD; petroleum, geothermal, and electricity are under the

MOEE; coal is under the Ministry of Mineral Resource and Environmental Conservation; civilian nuclear energy is under the Ministry of Education; energy efficiency and conservation is under the Ministry of Industry. Also, renewable energy is led by the Ministry of Education; Ministry of Agriculture, Livestock and Irrigation; MOEE; and Ministry of Mineral Resource and Environmental Conservation (M. M. Kyaw, 2017). This complicated structure needs to be streamlined if ministries and/or other institutions are to coordinate and align their priorities.

Lack of technical standards and codes

Without technical standards or codes, it is difficult to maintain a certain level of quality for mini-grids. Also, rules on how to deal with industrial waste, tar, and lead-acid should be established for sustainable development.

Threat of grid extension

Mini-grid operators are uncertain what will happen after the main grid reaches their customers' village. In theory, mini-grids are planned in areas that main grid are not expected to reach within 10 years. However, plans on the main grid's extension can change.

Lack of enforcement

Policy plans with some enforceability such as feed-in tariffs or renewable portfolio standards are needed to promote renewable energy. Discussions on draft regulations for the energy sector are now covering feed-in tariffs.

5.3.7 Barrier Framework, Policy Status, and Knowledge Gaps

Having developed a framework on the analysis of the barriers, one is now in a position to see which policy areas have received adequate attention and which ones remain unaddressed. Table 5-6 presents the current status of the different barriers based on the literature review.

As in other countries, the threat of central grid extension seems to be one of the most important barriers. The plan to introduce a mini-grid regulation framework will likely remove this barrier, but the draft is ongoing and not yet finalised.

Likewise, there is a programme to develop the financial sector, particularly to improve small and medium enterprises' access to finance (GIZ, 2017). This programme between Myanmar and a development partner is also not yet finished.

One interesting finding in this study is that Myanmar's long history of economic isolation has spawned domestic, indigenous technologies and business models though there seems to be some friction with respect to opening up the Myanmar market because of huge differences or gaps with international standards. This remains unaddressed, however.

Table 5-6. Barriers and Their Current Status

Barrier	Current status
Financial	The capacity development programme for the financial sector is in progress. It should provide mini-grid developers soft loans from international donor organisation through commercial banks (Greacen, 2017b).
Economic	Renewable energy-based mini-grids, especially solar PV, are capital intensive. It is reasonable to subsidise the initial costs of solar PV at the early stage, similar to the objective of the 60/20/20 programme. The ultimate aim is for the market to reach the stage where businesses can survive without subsidies. Demand is sure to grow but its speed is unclear.
Social/Cultural	Because of Myanmar's long isolation from the world, social/cultural differences are wider than in other countries. There are literatures that explain mini-grids in Myanmar from a social or cultural point of view. Indigenous business ecosystems of mini-grids in Myanmar should be evaluated, not dismissed.
Technical	Capacity building should fill in the knowledge gap. It should not be limited to developing new projects but should bring the knowhow of existing mini-grid operators of indigenous technologies up to par with international standards.
Regulatory	A regulatory framework that emphasises adherence to the law can decrease many regulatory risks (Pawletko, 2018; Greacen, 2018; Schmidt–Reindahl, 2018). However, there could be differences between legal expectations and reality, as gleaned from past experiences. It is not yet clear how to apply these regulations in actual practice.

PV = photovoltaic

Source: Authors.

5.4 Conclusions and Discussion

This chapter conducted an analysis of rural electrification and mini-grid support policies in Myanmar. A techno-economic assessment of renewable-based mini-grids was performed, which confirmed that there is economic sense to apply this technology in rural areas that are burdened with high diesel prices.

To analyse what hindered mini-grids' development other than economic factors, a comprehensive framework was develop, drawing on the broad literature and interviews conducted for the study. The resulting typology is similar to those already developed in existing literature but contains some novel elements such as the integration of domestic, indigenous technologies developed during Myanmar's economic isolation period.

The barrier analysis in this study is still in its early stage and has many limitations. Although backed by a review of literature and feedback from stakeholders, the resulting typology still needs further refinement. More importantly, it stopped short of providing a detailed analysis on how to remove each barrier through policy intervention and did not attempt to rank various barriers in the order of importance. No analysis on interactions (i.e., synergies or trade-offs) amongst barrier categories/subcategories was done. Such analyses could help further develop the rapidly changing mini-grid market in Myanmar and subsequently improve the conditions of residents in rural areas.