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Electricity Futures in the Greater Mekong Subregion: Towards Sustainability, Inclusive Development, and Conflict Resolution

Edited by

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Preface

International energy markets are experiencing a wave of innovations and the rise of new ideas and values. Remarkable examples of innovation include drastic cost reductions in the field of renewables and the digitalisation of energy systems. The International Energy Agency, in fact, notes that the 'solar photovoltaic is on track to be the cheapest source of new electricity in many countries.' This statement will have a significant impact on the future energy mix as well as energy policies of many countries. In addition, the Sustainable Development Goals of the United Nations, together with the spirit of the Paris Accord in 2015, are seeing some results and present an opportunity for both public and private sectors to work as partners towards common goals. Thus, we may be facing structural changes on energy's demand and supply sides.

Our research has focused on Myanmar and the Greater Mekong Subregion, emphasising rural electrification via renewable power generation through mini-grids as well as central-grid capacity expansion through sustainable power options. One of the purposes of this research is to analyse the current energy situation, including constraints in the region during this transitional stage, and to propose tangible policy recommendations that work towards energy security, environmental protection, and global warming mitigation.

Myanmar is the least developed country in the Greater Mekong Subregion and has the lowest electrification rate in the area; thus, it has room for further improvement. This is why most of the works are concentrated in the country. In fact, the problem is apparent in Myanmar with its sheer number of proposed large-scale hydropower plants; its strategic environmental planning, however, can disregard environmental damage.

Myanmar's abundant solar power can be further harnessed. The existing difficulties and inconveniences of the people in rural areas are real and urgent, and need to be solved as soon as possible. The people need energy in their daily lives now and in the future. In this sense, we have tried to consider their realities in the course of this research.

We have also realised that the issue on energy relates to many other broader concerns such as regional development, conflict and peace-building, national unity and security, poverty and wellbeing, democracy, water management, and equality and gender – most of which are included in the Sustainable Development Goals. Therefore, we came to understand that a wider and more conceptual view and approach are also required, particularly in Myanmar, where the democracy is fresh, and the government is confronted with ethnic and religious conflicts, especially in the rural areas.

Our team has tried to implement the research with a bottom-up approach as much as possible so as to consider the realities on the ground. For example, the team has continued to pay careful attention to the future of renewable mini-grid businesses and their indispensable role in the region's energy development. At the same time, as noted earlier, the team is just beginning to understand the issues from a higher point of view, taking other socially important values into consideration.

It should be noted that the energy policy in Myanmar could play a more important role in the future if it were designed and implemented in the way where its multifaceted nature was well considered, since many of the challenges included in the Sustainable Development Goals are real in Myanmar, and the role of energy and its access would be more appreciated here than in any other country.

Lastly but not least, I would like to express my sincere appreciation to the Economic Research Institute for ASEAN and East Asia for the continued support for our research.

Prof. Hisashi Yoshikawa

Working Group Co-leader (2018)

List of Abbreviations

ADB	Asian Development Bank
ASEAN	Association of Southeast Asian Nations
CPI	China Power Investment Corporation
DRD	Department of Rural Development
GEI	Global Environmental Institute
JICA	Japan International Cooperation Agency
LCOE	Levelised cost of electricity
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LIB	Lithium ion batteries
MOEE	Ministry of Electricity and Energy
MW	Megawatt
MWh	Megawatt hour
MoU	Memoranda of understanding
NEP	National Electrification Plan
NEMP	National Electricity Master Plan
NLD	National League for Democracy
PV	Photovoltaic
PARI	Policy Alternatives Research Institute
SWOT	Strengths, weaknesses, opportunities, and threats
SHS	Solar home system
US EIA	United States Energy Information Administration

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Executive Summary

Two years have passed since Daw Aung San Suu Kyi took office in 2016 as state counsellor of Myanmar, a key country in the Greater Mekong Subregion. Although the new administration has implemented various policies, the electric power sector has remained one of the bottlenecks to economic development. Urban areas continue to suffer from frequent blackouts, discouraging foreign investments in factories. Many rural residents have yet to enjoy modern electricity services. The lack of economic progress is one of the reasons ethnic conflicts continue in remote areas. This report's policy analysis of the Myanmar power sector aims to assist policymakers and stakeholders as it looks at electricity futures that foster sustainable and inclusive development, which then could help address the conflict issues.

Main-grid power development and connectivity

In 2014, the government of Myanmar released its power development plan for review. The plan contains a vast number of large-scale hydropower plants as well as coal-fired power plants, which could create a myriad of sustainability issues. In this study, a power capacity expansion model is thus used to analyse the impacts of the power sector policy. The analysis demonstrates that scenarios featuring variable and small-scale renewables and Association of Southeast Asian Nations (ASEAN) interconnections are not only environmentally friendly but also economically efficient (Table 1). A combined energy-hydrology model analysis was also conducted, which showed that removing the most damaging hydropower dams from the energy mix can still retain a significant amount of electricity generation capacities as well as will conserve the Salween (Thanlwin) and Irrawaddy (Ayeyarwady) river ecosystems by reducing sediment trapping.

Table 1. Summary of the Analysis Using a Power Capacity Expansion Model

Scenario	Notes	Estimated Capital Cost Expenditure
2014 National Electricity Master Plan	Follows guidelines and assumptions in the 2014 power development plan. In the original study, renewables are treated exogenously; renewables are added into the assumption mix and optimise endogenously.	US\$11.7 billion
Low-cost distributed energy resources	Follows current technology innovation and learning for renewable energy resources including solar photovoltaics, small-scale hydropower, wind, and energy storage facilities	US\$8.1 billion

ASEAN Power Grid (APG) Participation	Follows current technology innovation and learning while participating in an expanded power trade market for electricity imports and exports; APG includes 15 priority interconnection projects identified at the ASEAN level	US\$8.4 billion
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Source: Authors.

The analysis shows the importance of utility-scale solar photovoltaics, along with other renewables. A strengths, weaknesses, opportunities, and threats (SWOT) analysis of utility-scale solar energy in Myanmar was done as a preparatory step towards developing a solar policy framework. The Central Dry Zone is endowed with great solar resources and close to the main grid. In light of the global trend of ever-falling costs of solar photovoltaics, it would be possible to generate solar power at an affordable price. Solar plants can be built with a short lead-time so as to rapidly expand the generation capacity, which will help reduce the blackouts in urban areas. The question of how to streamline regulations for investment is an area that needs policy attention.

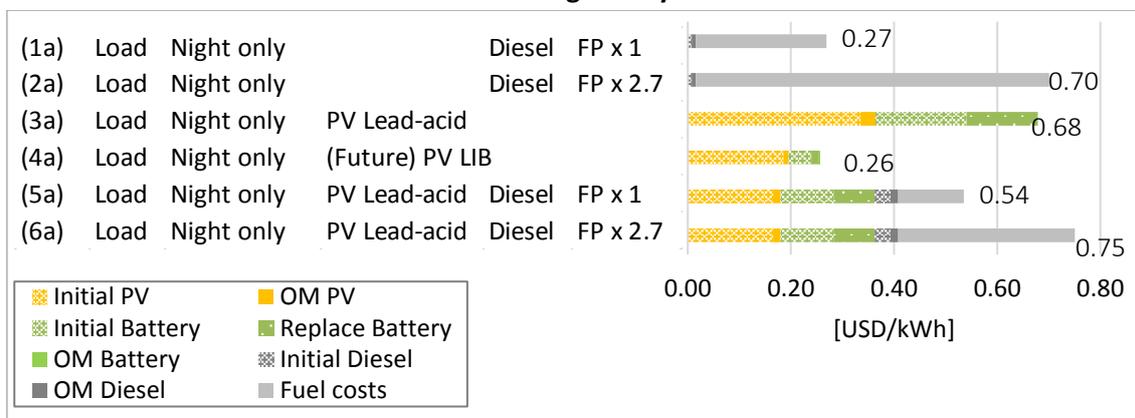
With regard to large-scale hydropower projects, the study conducted a case study on the Myitsone mega-dam project and analysed the decision-making process on the Chinese side. Findings show that the campaigns launched and the subsequent public sentiments against the Myitsone hydropower project led to the adoption of environmental and social guidelines on power plants in China. This guideline from China defines the responsibility of their investors over the environmental and social impacts of their investment activities on host countries.

Rural electrification with renewable-based mini-grids

The Myanmar government has set the goal of universal electrification by 2030. To accelerate rural electrification, the nation should look at all possible solutions: main-grid extension, solar home systems (SHSs), and mini-grids. In particular, mini-grids can be used not only for lighting and mobile charging but also for entertainment purposes as well as productive uses. One of the barriers to the wide diffusion of mini-grids is stakeholders' lack of an understanding of both the financial and non-financial aspects of renewable-based mini-grids.

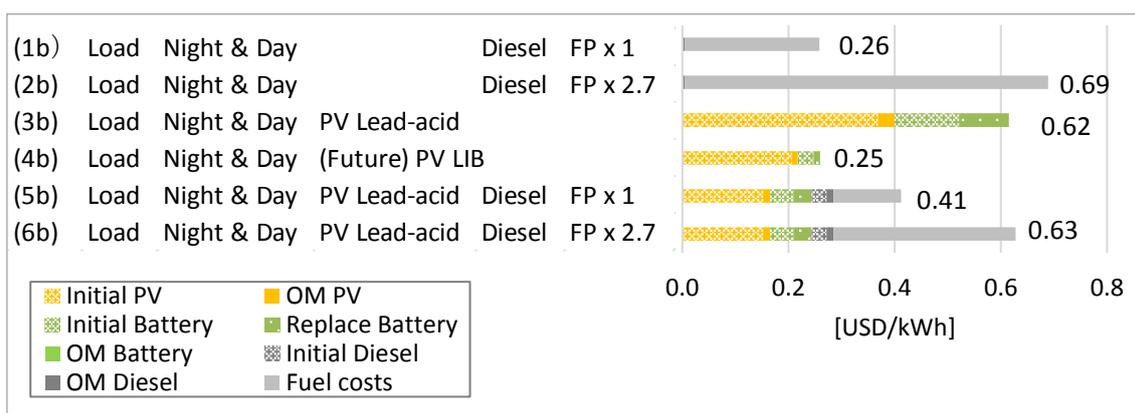
The financial viability of mini-grids was assessed by calculating the levelised costs of electricity for various types of mini-grids (Figures 1 and 2). Compared to the currently dominant diesel option, mini-grids for renewables are found to be economically viable, especially in remote rural areas faced with high diesel prices.

**Figure 1. Levelised Costs of Electricity of Different Mini-Grid Configurations:
For Cases With a Night-Only Load Profile**



PV = photovoltaic; OM = operation and maintenance; LIB = lithium ion battery; FP = fuel price
Source: Authors.

Figure 2. Levelised Costs of Electricity of Different Types of Mini-grids: For Cases with a Load Profile for Both Day and Night



PV = photovoltaic; OM = operation and maintenance; LIB = lithium ion battery; FP = fuel price.
Source: Authors.

Despite good economic prospects, the distribution of mini-grids has been slow. This shows that there is a need to understand the barriers to the development of mini-grids in Myanmar. Table 2 shows the barriers to mini-grid development, based on the literature review and discussions with stakeholders and experts. The study found that although Myanmar shares a common problem with low electrification with other developing countries, certain issues such as indigenous mini-grid technologies are unique to Myanmar and deserve careful consideration.

Table 2. Barriers to the Development of Mini-grids

Category	Sub-categories
Financial	Access to financing, high capital cost, insufficient capital (developer), Insufficient capital (consumer), currency risk, long payback period.
Economic	High transaction costs, small market size, low demand, tariff structure: (cost-revenue gap), customers' ability to pay, revenue collection uncertainty
Social/cultural	Negative externalities caused by international organisations, education, community acceptance, geographical difficulty, perception of inferior quality, theft and non-technical loss, shared resource
Technical	Indigenous technology, lack of local expertise, durability and quality, operation and maintenance, intermittency, lack of interoperability with main grid
Regulatory	Lack of regulatory framework, institutional capacity, lack of technical standards and codes, threat of grid extension, lack of enforcement

Source: Authors.

Policy Recommendations

Based on its results, the study provided the following policy recommendations:

Main-grid capacity expansion

- Alternative power development plans that exclude those large-scale hydropower plants contributing the most damage to the environment can help towards ecological and social stability while achieving economic efficiency. In addition, Myanmar can take advantage of the falling cost of solar electricity by making a strategic priority in the power development plan.

Rural electrification through renewables-based mini-grids

- To accelerate the diffusion of mini-grids, businesses' use of electricity during daytime hours in rural areas should be encouraged to make mini-grid businesses sustainable. It is also crucial to create a supportive financing scheme for mini-grid developers/operators. Finally, the establishment of technical standards and codes for renewable energy equipment is urgently needed.
- To better achieve effective and strategic electrification, a single governmental body should be responsible for both on-grid and off-grid measures.

Investment environments and connectivity

- Participation in a regional power grid markets (e.g., Greater Mekong Subregion, ASEAN Power Grid, and the South Asia Subregional Economic Cooperation) will provide Myanmar an opportunity to expand its access to electricity, meet rising urban power demand, and minimise environmental and societal risks.
- International society should help secure communication lines between foreign investors and Myanmar's local communities as early as the pre-project phase of large-scale hydropower developments.
- The government of Myanmar should prioritise the development of a policy framework that will streamline investments (e.g., for utility-scale solar).

Chapter 1

Introduction

Myanmar's sustainable development heavily depends on the appropriate improvement of its power sector. Its transition from military rule to democracy has brought in international assistance and private investment interests, paving the way for new resources and alternatives for the government to develop its energy-related policy programmes. The government's policy programmes have benefited from the support of international donors and cover the Energy Master Plan (Asian Development Bank), the National Electrification Plan (World Bank), and the National Electricity Master Plan (Japan International Cooperation Agency). In a rapidly changing environment, there is a need to review these programmes as they are being implemented, or they may even have to be updated before implementation.

This report analyses most of the salient points in Myanmar's policies for the power sector. The guiding research questions are: How can Myanmar's future electricity sector be sustainable and conducive to inclusive development, and contribute to conflict resolution? What kind of policies will be able to assist such progress? These questions are examined from both the main-grid and off-grid perspectives.

As the related issues are wide-ranging, multiple methods are used to explore the future of Myanmar's electricity sector. Table 1-1 shows the structure of the report. The outputs and recommendations are the result of desk research and numerous engagements with local and international stakeholders through workshops, seminars, interviews, as well as one-on-one discussions.

Table 1-1. Structure of the Report

Category	Chapter	Issue and Method
Overview	Chapter 2	Recent policy development; literature review
On-grid issues (including connectivity)	Chapter 3	Power development plans; Energy/environmental modeling
	Chapter 4	Solar photovoltaics deployment; SWOT analysis

Off-grid issues	Chapter 5	Rural electrification with mini-grids; techno-economic modeling and barrier analysis
Foreign investment	Chapter 6	The Myitsone Dam; analysis of policy process

SWOT = strengths, weaknesses, opportunities, and threats

Source: Authors.

Chapter 2 provides an overview of Myanmar’s power-sector policy, focusing on recent developments. The country’s electricity supply is still very low, both in terms of its quantity and quality.

Chapter 3 analyses opportunities for the sustainable development of the large hydropower potential of the country. In particular, it explores an optimal dam portfolio from a sediment trapping point of view. The current government’s capacity expansion plan is found to have a severe impact on the ‘health’ of the basins. An alternative hydropower development plan that excludes the most damaging ones can reduce the impact while maintaining the electricity generation and economic development activities. This would also allow for the development of power generation from solar, natural gas, biomass, and small hydro plants, which can substitute for power generation from large-scale hydropower.

Chapter 4 looks at the possible role of utility-scale solar energy. Myanmar, a key state in the Greater Mekong Subregion, is far behind neighbouring countries and global trends in terms of turning to solar generation. Previous studies revealed that there is a high technical and economic potential in the nation, especially in the Central Dry Zone. Using a strengths, weaknesses, opportunities, and threats (SWOT) framework, the chapter sheds light on the drivers and bottlenecks of a solar energy strategy in Myanmar.

Chapter 5 discusses the potentials of mini-grids for rural electrification and analyses the barriers to the deployment of such option in Myanmar. In particular, the use of clean energy sources should be preferred over fossil fuels. This study first calculates the levelised cost of electricity (LCOE) of diesel, solar + battery, and solar + battery + diesel mini-grids, using data collected from private developers in Myanmar. Then, the barriers for renewable energy-based mini-grids in Myanmar are explained based on data from existing literature as well as interviews conducted with different stakeholders, such as officers from international development organisations,

private companies, nongovernmental organisations, and local researchers.

Chapter 6 explores the suspension of the Myitsone mega-hydropower project, and traces the process behind the publication of the social and environmental guideline for China's projects in foreign countries. A framework called the Issue Attention Cycle model, which was originally found in democratic institutions, was discovered to be applicable to the Chinese socialistic decision-making process. This has a policy implication on how Myanmar should deal with foreign investments for its future power projects.

Chapter 7 concludes with policy recommendations for Myanmar's power sector and related policy areas.

Chapter 2

Overview of Myanmar Energy Situation

Myanmar is experiencing a major political, economic, and social transition from what was once under a military regime to today's open democracy. In this process, electrification of the country is expected to play a fundamental role in its development.

The energy policy landscape of Myanmar remains in flux. A new minister of Energy and Electricity was appointed in 2017, bringing new perspectives to the ministry. Liquefied natural gas (LNG) was chosen as a strategic option in the face of rising energy demands. Four projects were approved and expected to start operation by 2021. Meanwhile, liquefied petroleum gas (LPG) has been recently targeted as a means to reduce the electricity consumption in urban areas.

Coal remains a highly disputed resource. The union government has explicitly refused to continue its development, while the Kayin state government is working to support a 1,280 MW coal-fired project. In all these, one needs to also remember that rapid urbanisation will continue to drive the electricity demand in major cities.

In rural areas, on the other hand, the government has made some headways in its support for mini-grids. Recent policy directions have been focusing on the formulation of regulations for off-grid projects.

2.1 Background: Myanmar Transition from Military to Democracy

Myanmar, formerly known as Burma, is the largest country in continental Southeast Asia. It is even slightly larger than Thailand. It is a multi-ethnic country, with 135 different groups recognised. Majority is composed of ethnic Burmese, while other large groups include Chin, Kachin, Karenni, Karen, Mon, Rakhine, Rohingya, and Shan (Oxford Burma Alliance, n.d.).

The country was under various phases of British colonial control between 1824 and 1948, after the defeat of the Burmese monarchy in three wars. A British-like administration was attempted to be introduced during this period (Thant Myint-U., 2008). After it obtained its independence

in 1948, Myanmar entered its democratic era. It then experienced a period of military dictatorship after General Ne Win staged a *coup d'état* in 1962.

Myanmar initiated a gradual opening and transition towards democracy in 2008. A new constitution was approved and elections were held. U Thein Sein, who became president in 2007 and led the transition towards democratic elections, was in charge of this process. After the elections in 2012, the National League for Democracy (NLD) won most of the seats. The NLD was the main party opposing the military rule and founded by Aung San Suu Kyi, the main figure of the opposition, daughter of the country's hero Aung San, and Peace Nobel laureate (Rieffel, 2016).

The NLD achieved a landslide victory during the 8 November 2015 election (Hulst, 2015; Whiteman, 2016). However, Aung San Suu Kyi did not become president because the constitution does not allow locals from assuming the presidency if they have foreign family members (Cochrane, 2017). Instead, her close ally U Htin Kyaw became president, while the new position of state counsellor was created for her (Mclaughlin, 2016).

2.2 Energy Sector in Myanmar: Country-wide Implications

Energy is expected to play a central role in the democratisation and modernisation of Myanmar (Loftus, 2016). However, the nation's electrification rate as well as the consumption of electricity remain very low.

In urban areas, the reliability of the supply remains an issue. A successful country-wide electrification process also affects the legitimisation of the reform agenda in Myanmar (Ross, 2015). Myanmar needs to also increase its generation capacity to meet the needs of the population and the rapid rise in urban population and industry. Moreover, to be consistent with the United Nations Sustainable Development Goals and the Paris Agreement, Myanmar must meet such goals in a sustainable and inclusive manner by harnessing the potential of renewable energy.

Myanmar is eminently rural (Table 2-1), with the exception of Yangon, the former capital city and still the country's major economic hub.

Table 2-1. Population in Administrative Divisions in Myanmar

State / Region	Male	Female	Total	% of Total	Area (sq km)	Urban Area (%)	Rural Area (%)
Kachin	878,384	811,057	1,689,441	3	89,041.80	36	64
Kaya	143,213	143,414	286,627	1	11,731.51	25	75
Kayin	775,268	798,811	1,574,079	3	30,382.77	22	78
Chin	229,604	249,197	478,801	1	36,018.90	21	79
Sagaing	2,516,949	2,808,398	5,325,347	10	93,702.48	17	83
Tanintharyi	700,619	707,782	1,408,401	3	43,344.91	24	76
Bago	2,322,338	2,545,035	4,867,373	9	39,404.43	22	78
Magway	1,813,974	2,103,081	3,917,055	8	44,820.58	15	85
Mandalay	2,928,367	3,237,356	6,165,723	12	30,888.09	35	65
Mon	987,392	1,067,001	2,054,393	4	12,296.64	28	72
Rakhine	1,526,402	1,662,405	3,188,807	6	36,778.05	17	83
Yangon	3,516,403	3,844,300	7,360,703	14	10,276.71	70	30
Shan	2,910,710	2,913,722	5,824,432	11	155,801.38	24	76
Ayeyawady	3,009,808	3,175,021	6,184,829	12	35,031.88	14	86
Nay Pyi Taw	565,155	595,087	1,160,242	2	7,075.10	32	68
Union	24,824,586	26,661,667	51,486,253	100	676,577.23	30	70

Source: Ministry of Immigration and Population (2015).

Myanmar has become one of the fastest growing countries in the region: up until 2014, its economic growth had been constantly above 7% (Lwin, 2015) (Table 2-2). Its low labour cost has made Myanmar an attractive location for manufacturing industries (Matsui, 2017b). Nevertheless, natural gas has traditionally been, and still is, the largest export product of the country and the main source of foreign currencies during its period of isolationism. Myanmar

exports about 90% of its natural gas production from four active gas fields, signing export contracts with countries such as Thailand and China. Agriculture constitutes the main part of the national economy – about 38% of the GDP – and employs 60% of the population (World Bank, 2016a). It also comprises 25% to 30% of the export earnings (FAO, 2018). It is commonly said that anything can be planted in Myanmar because the soil is considered to be the most fertile in Asia (Zorya, 2016). Nevertheless, isolation and stagnation have led the country to be the least profitable in the region. In 2015, the government decreed a rice export ban for six weeks (Wai and Aung, 2015). Tourism has been growing and the government has tried to stimulate it; however, it still is largely limited by political factors.

Table 2-2. Economic and Trade Indicators

Indicator	2000	2005	2010	2011	2012	2013	2014	2015
Population (million)*	47.67	49.98	51.73	52.13	52.54	52.98	53.44	53.90
GDP (current US\$ billion)*	8.90	11.97	49.54	59.98	59.73	60.13	65.57	62.60
GDP growth (%)*	13.75	13.57	13.08	11.99	10.26	10.55	9.63	5.59
GDP per capita (current US\$)*	187	239	958	1,151	1,137	1,135	1,227	1,161
Human Development Index (HDI)**	0.427	0.474	0.526	0.533	0.540	0.547	0.552	0.556
Inflation (average consumer prices)***	15.63	48.499	97.379	96.314	100.855	107.164	113.72	123.33
FDI approved (US\$ million)****	-	6,065	19,999	4,644	1,419	4,107	8,010	9,481
FDI, net inflows (current million US\$)*	255	235	901	2,520	1,333	2,254	2,175	4,083

FDI (%GDP)*	2.86	1.96	1.82	4.20	2.23	3.75	3.32	6.52
Import value index (2000 = 100)*	100	80.48	200.75	380.40	388.10	507.93	684.39	738.34
Export value index (2000 = 100)*	100	233.09	534.58	570.19	547.90	693.31	680.84	685.49
Exports (US\$ million)*	-	-	8,829	10,228	10,379	11,957	14,653	16,459
Imports (US\$ million)*	-	-	8,184	10,453	12,499	13,987	16,341	18,403

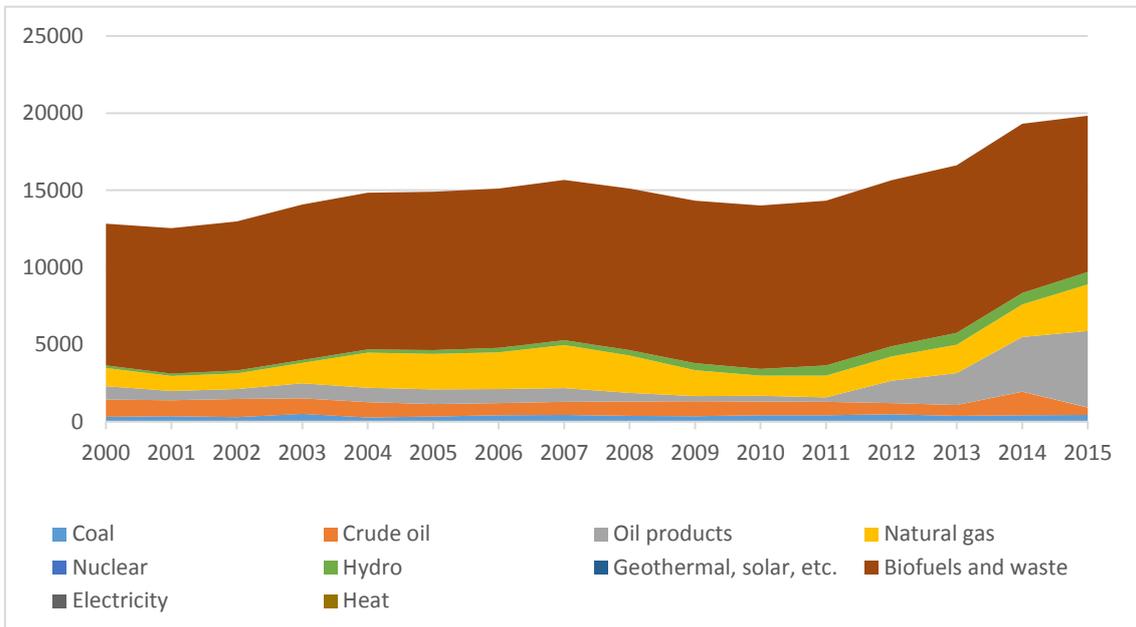
Sources: *World Bank (WB), **United Nations Development Programme (UNDP), ***International Monetary Fund (IMF), ****Directorate of Investment and Company Administration (DICA).

2.2.1 Energy Demand and Usage in Myanmar

Myanmar's energy supply is highly dependent on traditional biomass. Figures 2-1 and 2-2 show the total primary energy supply and final consumption in the 2000s. From about 70% at the beginning of the century, the portion of biofuels and waste in the total energy supply has only slightly dropped to 60%. Today, oil products have been experiencing an abrupt increase since 2011. Meanwhile, natural gas production and consumption have remained relatively stable. The contribution from coal has not been significant.

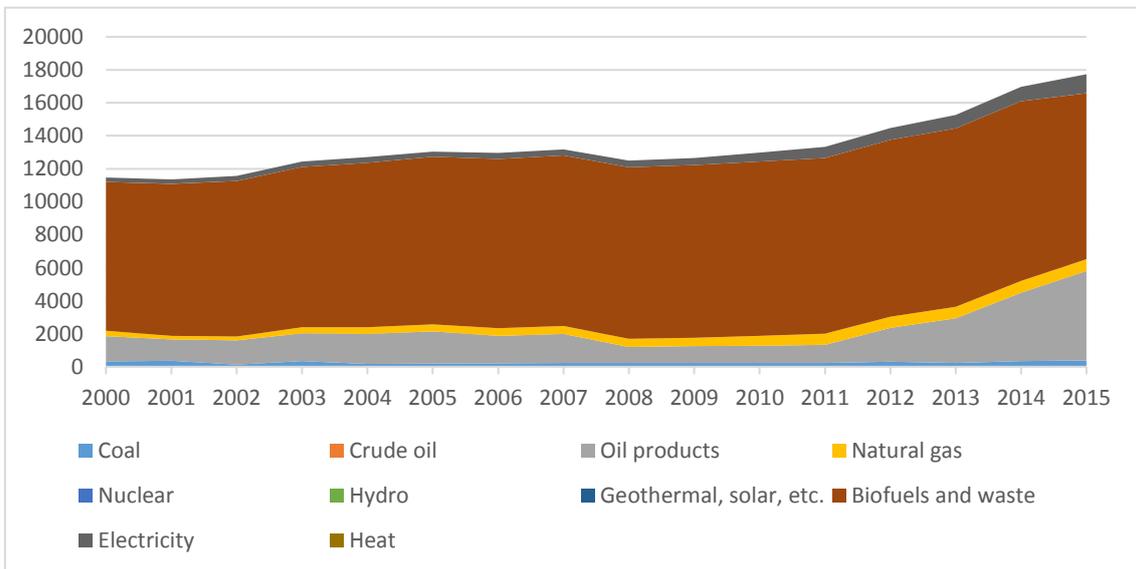
The residential sector is the largest energy consumer, as seen in Figure 2-3, although consumption by the transport sector has been growing in the last decade. Meanwhile, industry has remained stable at about 10%–12% of the total consumption. Other sectors' consumption continues at much lower levels.

Figure 2-1 Total Primary Energy Supply (ktoe)



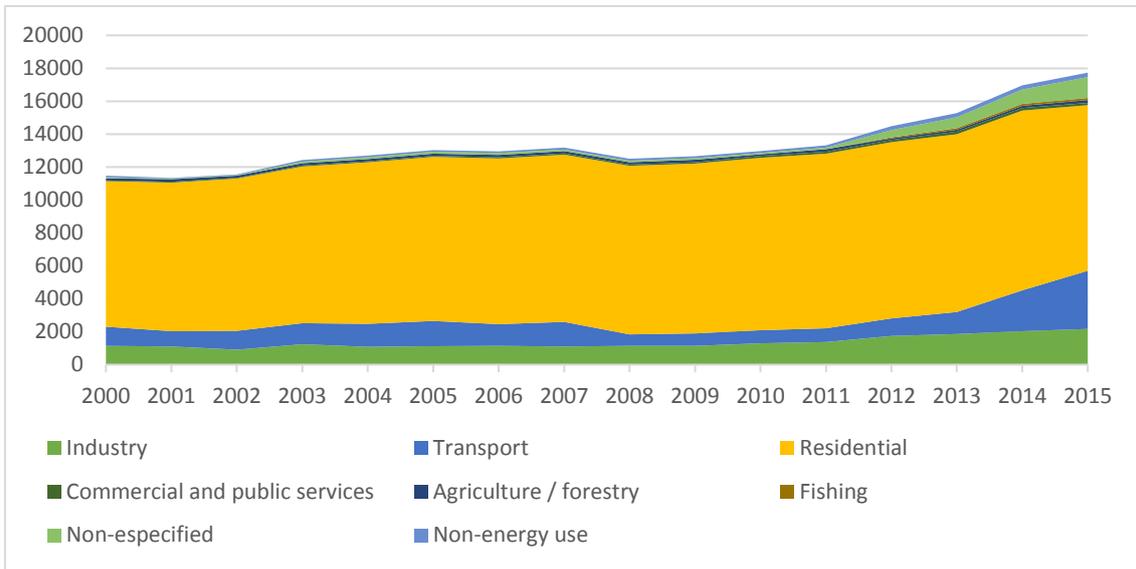
Source: International Energy Agency data.

Figure 2-2 Total Final Consumption (in ktoe)



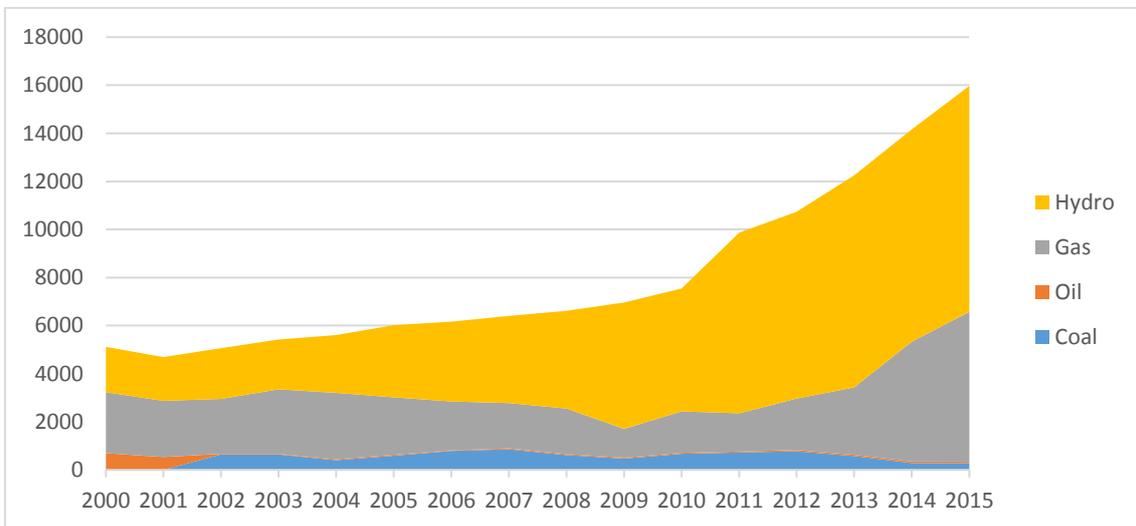
Source: International Energy Agency data.

Figure 2-3 Total final consumption by sector (ktoe)



Source: International Energy Agency data.

Figure 2-4. Electricity Production (GWh)



Source: International Energy Agency data.

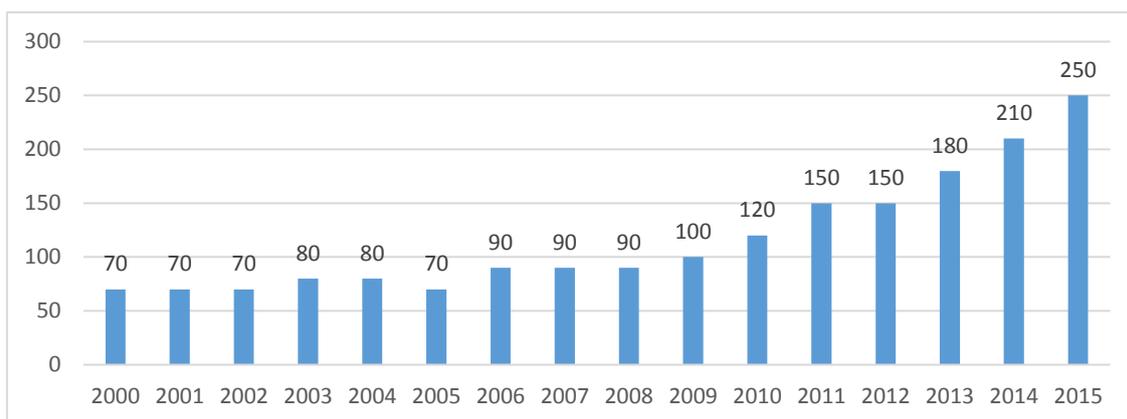
2.2.2 Rising Electricity Demand

Myanmar’s electricity production was near 16,000 GWh in 2015 – a two-fold increase since 2010. The generation mix is dominated by hydropower and gas. Hydropower constitutes between 60%

and 70%, while natural gas accounts for the remaining 30%. Other sources comprise only a minority in the mix.

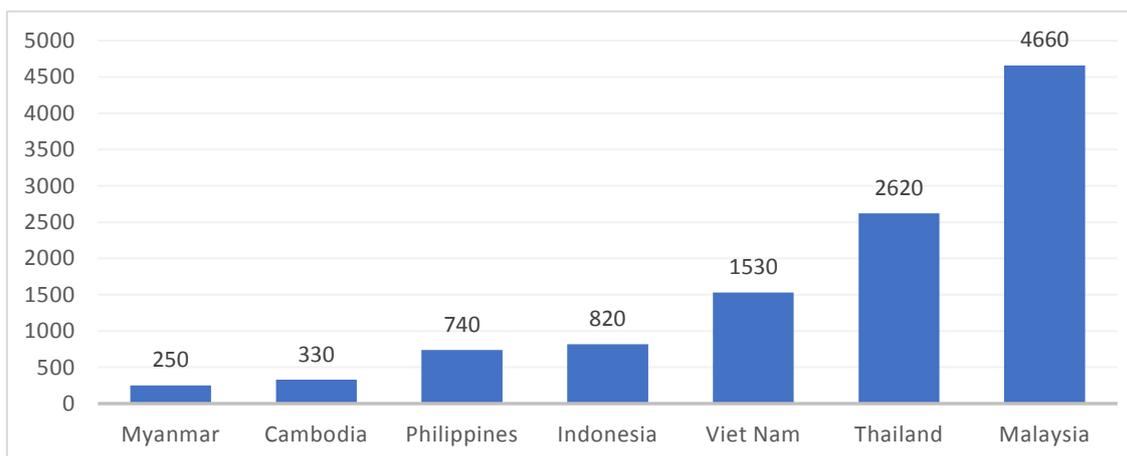
Figure 2-4 shows the rise in electricity production, which is accompanied by the rapid increase in electricity consumption per capita (see Figure 2-5). This notwithstanding, Myanmar remains to have the lowest electricity consumption per capita amongst ASEAN countries (see Figure 2-6).

Figure 2-5. Electricity Consumption Per Capita (kWh/capita)



Source: International Energy Agency.

Figure 2-6. Electricity Consumption In Selected ASEAN Countries (kWh/capita, 2015)



Source: International Energy Agency data.

2.3 Two-pronged Power Sector Challenge in Myanmar's Rural Electrification, Generation Expansion, and Tariff Reform

Myanmar is facing a two-pronged problem in the power sector. On one hand, a large portion of the population has none or little access to electricity; on the other hand, the population connected to the national grid experiences frequent blackouts.

2.3.1 Rural Electrification

Although there are varied figures available on Myanmar's access to electricity, all sources agree that at least half of the population lacks access to modern electricity. Furthermore, most electrified rural communities rely either on diesel generators, which are economically and environmentally costly; or on solar home systems, which do not provide sufficient power for productive uses.

The government of Myanmar aims to achieve universal electricity access by 2030. The National Electrification Plan, prepared with support from the World Bank, foresees that this will be achieved mainly by expanding the national grid. However, a shift towards decentralised alternatives such as mini-grids is gaining wider support. The Department of Rural Development (DRD) is Myanmar's leading governmental agency for rural electrification. The Electricity Law of 2014 favours decentralising the decision-making process for small off-grid projects. The Ministry of Electricity and Energy's (MOEE) approval is therefore not needed for projects of less than 30 MW and not connected to the national grid. The DRD has a wide network of representatives across the country that facilitates its work with local communities. Nevertheless, an inefficient coordination between the MOEE, which is in charge of the national grid, and DRD, which is under the Ministry of Agriculture, Livestock, and Irrigation, can become a drawback in the realisation of grid-ready projects.

2.3.2 Expansion of Generation Capacity

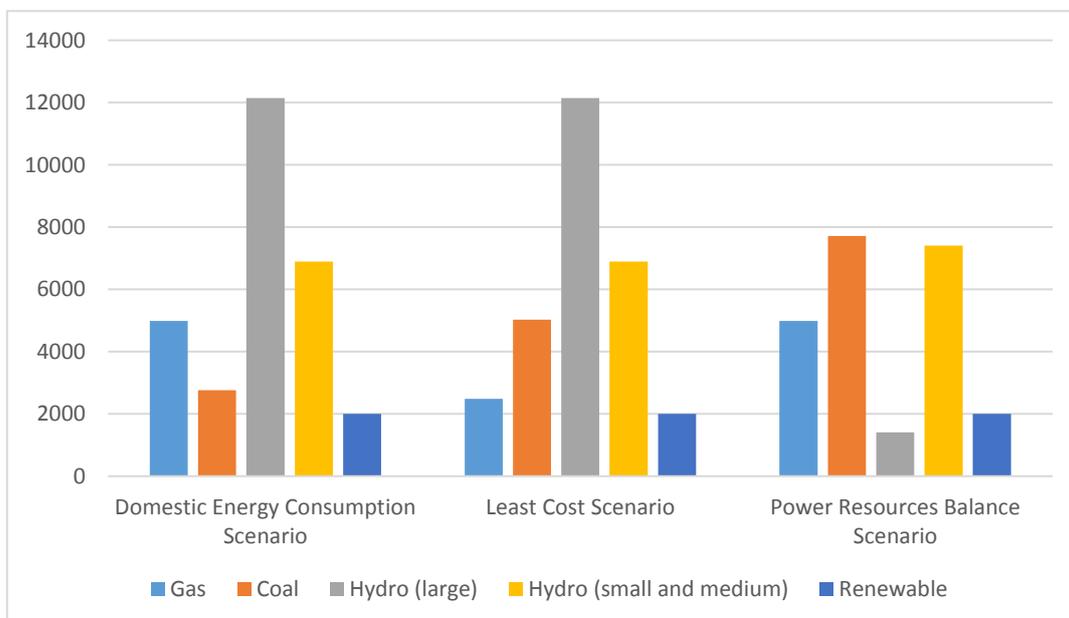
Increasing Myanmar's generation capacity is a priority of the government. The National Electricity Master Plan (NEMP), which the nation prepared with support from the Japan International Cooperation Agency (JICA), analysed three possible scenarios for capacity expansion:

- 1) **Domestic Energy Consumption Scenario:** maximisation of domestic power generation. Hydropower and gas-fired plants are fully developed.
- 2) **Least Cost Scenario:** minimisation of overall generation cost. Coal-fired plants' contribution increases, while that of gas-fired generation decreases.
- 3) **Power Resource Balance Scenario:** feasibility of projects is also considered. Only hydropower plants with shorter lead-time and nearest to demand centres are developed. Gas-fired generation is developed but constrained by secured fuel supply. Coal-fired generation compensates the reduction in gas and hydro-power sources.

The Power Resource Balance Scenario was finally selected for the plan. Nevertheless, the large-scale development of coal-fired generation plants has become very controversial. Currently, the central government does not support the commissioning of new coal-fired generation plants.

The contribution from renewables as an exogenous assumption was set at 10% of the energy capacity in the NEMP. The role of variable renewables eventually lessened. In Chapters 3 and 4, such potential as well as barriers to the penetration of solar energy in the generation mix are explored.

Figure 2-7. Installed Capacity by Scenario and Source in the NEMP by 2030 (MW)



NEMP = National Electricity Master Plan.

Source: Japan International Cooperation Agency (2015).

2.4 Update on the Myanmar Power Sector

2.4.1 Power Demand Will Continue Rising with New Mega-development Plans in Urban Areas

Myanmar's economy is expected to continue to grow in the coming years (Rab et al., 2016). Urban areas are experiencing a refurbishing of the inner areas as well as expanding to adjacent townships. Yangon, for example, has new development projects. With assistance from JICA, the local government is drafting the Yangon 2040 Master Plan (Aye, 2017; JICA and YCDC, 2014), which includes plans on a new airport, a second special economic zone, and access to a deep-sea port (Mon and Aye, 2016). The Yangon New City project will extend Yangon to the other side of the Yangon River. Its specially created authority, the New Yangon Development Company Limited, has proposed a public–private partnership-based development of the 30,000 acre (about 121 sq km) area, of which 20,000 acres will be developed during the first phase (Ko, 2018; Shine and Ko, 2018). The Union government has also presented four large-scale development projects in Yangon and Mandalay recently (Tha, 2018). All these initiatives represent an opportunity to integrate rooftop solar systems in the urban development process.

2.4.2 Political Re-shuffle

The year 2017 saw a reshuffle of leadership at the MOEE and the country's national government. In July 2017, U Win Khaing was appointed as the new minister of Energy and Electricity, replacing U Pe Zin Tun while remaining as head of the Ministry of Construction (Lynn, 2017a). After Myanmar's President U Htin Kyaw resigned, U Win Myint was appointed to the position in March 2018. Both are seen as loyal allies of Aung San Suu Kyi (Nang and Paddock, 2018).

The new energy minister identified his minister's new priorities. In his first interview with international media outfit Reuters (Lewis and Naing, 2017), the minister pointed out that: (i) hydropower remains a priority, but in the future, no large dams are expected to be constructed *before* 2025; and (ii) imports of LNG and small-scale hydropower projects will be prioritised, with LNG to be used as part of the base load.

2.4.3 New Minister Advocates for Securing Supply in the Short Term: The Rise of LNG in the Power Generation Mix and a Boost for LPG

The new minister strongly emphasised the need to increase the generation capacity in the fastest

possible manner. Such priority facilitated the speedy approval of the construction of four new generation facilities, of which three are using imported LNG (Table 2-3). These are expected to be operational, at least partly, by 2020. Some memoranda of understanding (MoUs) have been signed with the MOEE while the signing of the power purchase agreements is still pending. The final agreement on the price to be paid by the government will be critical in the sustainability of the sector (Kean, 2018b).

Table 2-3. New Natural Gas and LNG Power Generation Projects Approved in 2018

Power plant	Capacity (MW)	Fuel	Consortia	Estimated Cost (US\$ million)
Ahlong	356	LNG to power, FSRU	Toyo–Thai	321
Kanbawk	1,230	LNG to power, FSRU	Total and Siemens	
Kyaukphyu	135	Combined-cycle gas turbine (natural gas from Shwe)	Sinohydro and Supreme	180
Mee Laung Gyaing	1,390	LNG to power, FSRU	Zhefu and Supreme	2,507

FSRU = Floating Storage Regasification Unit; LNG = liquefied natural gas.

Source: Kean (2018).

Liquefied Petroleum Gas has been identified recently by the government of Myanmar as a way to reduce the consumption of electricity in urban areas. The current number of households that utilise LPG for cooking is very low; a shift in consumption to LPG is seen as an opportunity to ‘free up’ the nation’s power generation capacity (K. Kyaw, 2018). The target is to increase the consumer base of LPG users from the current 100,000–150,000 households to 1 million–1.5 million households by 2020 (Htoon, 2018; K. Kyaw, 2018).

There are a number of challenges the government must overcome to be able to scale up the use of LPG. Adequacy of safety standards is the most worrisome (Chern et al., 2018). Myanmar has also little capacity to generate LPG and to meet most of the current consumption demand. The country demands 6,500 tons of LPG per month, of which 5,000 tons are currently being imported

(Eleven, 2018). Constraints in the supply chain and inadequate investments in the sector are also identified as drawbacks (Chern et al., 2018).

2.4.4 Coal

The merits and downsides of coal-fired generation of electricity remain a highly deliberated issue. The Union government does not favour any further development of the coal-fired electricity and coal mining plants (Phyo, 2017). Nevertheless, a 1,280 MW coal-fired project in the Kayin state has triggered a debate between the central and regional governments.

In the state government's proposal, the project would be built near Hpa-an, the capital of Kayin, by Toyo–Thai for US\$2.8 billion (Mon, 2018). The state government reasoned that the project is necessary to increase electrification and attract more foreign investments (Myint, 2017a). Part of the public, however, opposed the project, claiming that there was lack of transparency in the process (Han, 2018; Naing, Lee, and Yimou Lee, 2017; S. P. Win, 2018).

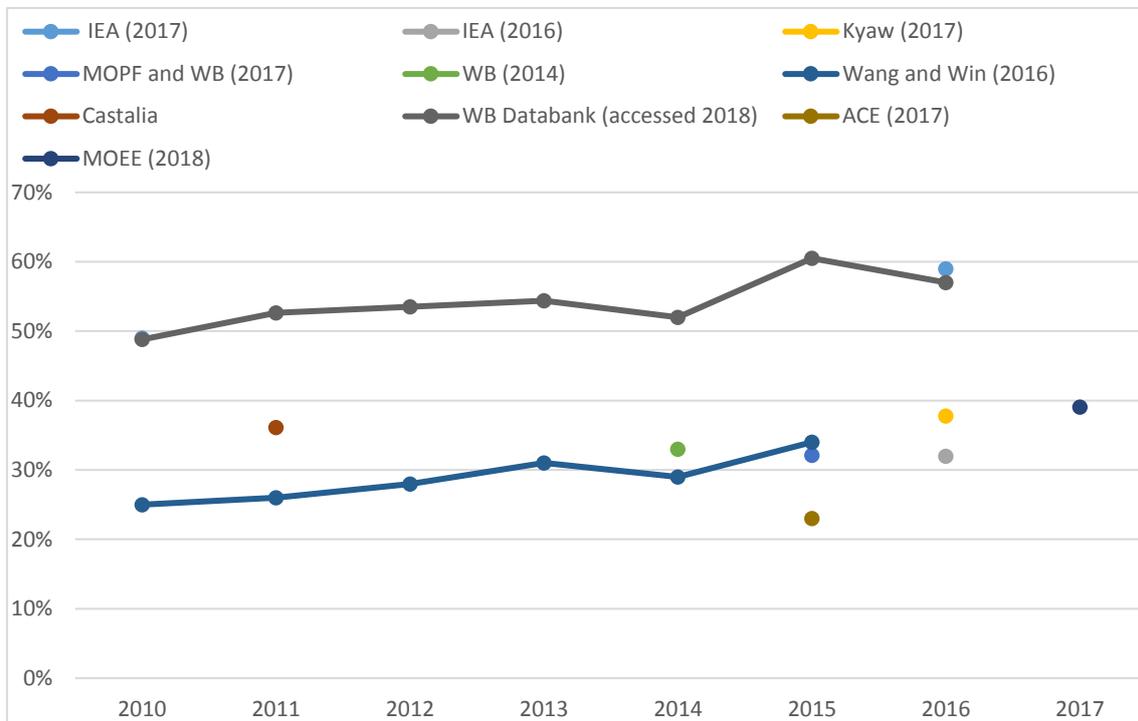
The Union government has, thus, stopped the project by virtue of the Electricity Law, which limits state governments' authority to approve power generation projects to those that are up to 30 MW only and not connected to the national grid (Htwe, 2017b; S. M. Mon, 2018b).

2.4.5 Rural Electrification Policy

The Myanmar government has set the goal of universal electrification by 2030, consistent with Goal No. 7 of the 2015 United Nations Sustainable Development Goals. To explore how to transition from the current situation to the desired state, it is crucial to understand the current level of electrification. Numbers vary from report to report, however Figure 2-8 shows the varying electrification rates based on different definitions, which makes it difficult to determine the actual rate. According to a report that looked at electrification in detail (Myanmar Ministry of Planning and Finance and Bank, 2017), the breakdown shows electrification through the main grid of 32.5%; by communal or private grids, 10.6%; by SHS, 17.4%; by rechargeable battery systems, 17.2%; and by others (e.g., power generator, solar lantern), 6%.

Most figures on electrification through the main grid are in the 23% to 32% range (ACE, 2017; MOPF and World Bank, 2017). It seems that the main grid's electrification rate is in the low 30% range, growing to 40% when mini-grid connections are included, and jumping to around 60% if SHSs are included.

Figure 2-8 Electrification Rates From Multiple Sources



Notes: International Energy Agency (2017a and 2016) and World Bank Databank (2018): for % of population.

Myanmar Ministry of Planning and Finance and Bank (2017): % of population weighted, connected to main grid only.

M. M. Kyaw (2017), World Bank (2014), Wang and Win (2016), and Ministry of Electricity and Energy Myanmar (2018): % of households.

Castalia Strategic advisors (2014): % of connections, national average excluding Yangon.

ASEAN Centre for Energy (2017): % grid-connected.

Under the National Electrification Programme funded by the World Bank, an initiative called '60/20/20' has been conducted since 2016 to encourage the installation of renewable energy-based mini-grids. The scheme involves the government subsidising 60% of the capital costs while villagers and developers/operators invest 20% each. This has proven to be a great incentive for developers, as the number of projects had increased from eight in the first year to 74 accepted project proposals by 2018 (Frontier Myanmar Research Ltd., 2018).

On the regulatory front, the World Bank and Deutsche Gesellschaft für Internationale Zusammenarbeit are working on a regulatory framework. Rather than instituting a new law, they are revising the present law known as the 2014 Electricity Law to institutionalise mini-grids. With this revision, the treatment of mini-grids will be facilitated. The framework will cover, for instance, the approval/licensing of mini-grid applications, permission for tariff setting with a reasonable profit, and options to take when the main grid arrives earlier than planned. Mini-grids connected to the centralised grid are expected to be under the jurisdiction of MOEE, while mini-grids that are not connected and therefore operate autonomously will be under the jurisdiction of state/regional governments (Pawletko, 2018; Greacen, 2018; Schmidt–Reindahl, 2018).

However, how the framework will be operationalised after the revision is still unclear. For example, the 2014 Electricity Law states that an ‘electricity regulatory commission’ should administer electricity activities, but such commission does not exist yet (Polastri Wint and Partners, 2014).

Chapter 3

Myanmar Power Development Pathways for Low Costs and Low River Impacts

This chapter describes Myanmar's national energy expansion strategy. Next, in its analysis, this chapter combines an energy planning model with the strategic planning of hydropower dam portfolios that aim to simultaneously reduce the overall power cost as well as the sediment impact loss from the most damaging hydropower development projects. Sediment loss is an indicator of the level of environmental health and loss of land for agricultural production.

The modelling results demonstrate that renewables (excluding large-scale hydropower) and participation in the ASEAN power grid have a great potential to sustain the future of Myanmar's electricity supply.

3.1 Introduction

Myanmar's currently massive energy deficit hinders its economic development. Hence, expanding its energy production capacity is a national priority. Channelling investment funds towards low-cost and low-impact projects remains a key policy issue, given the ongoing tension over hydropower development and other electricity options.

Myanmar's power system is set to expand rapidly following an influx of foreign direct investment and multilateral development bank efforts to increase the country's access to electricity from around 33% to 100%. These imminent investments in renewable and non-renewable sources of electricity will determine the environmental and economic performance of Myanmar's electricity supply for the coming decades. Myanmar's territory includes the Salween and Irrawaddy Rivers, both harbouring considerable hydroelectric potential that could lay the foundation for the country's future in renewable energy use. Fully developing Myanmar's hydropower potential would, however, also lead to major long-term environmental impacts, such as on the basins' sediment budgets.

Myanmar's current power development plan features substantial expansion of hydropower and coal-fired power plants and downplays the possible expansion of other renewable resources such as solar energy. Previous analyses have not properly considered the great potential of solar power, nor did they pay attention to the environmental impact of large-scale hydropower. Additionally, research works linking the capacity expansion of the energy sector with its ecological impacts cannot be discounted. In Malaysian Borneo, for instance, the proposed Sarawak Corridor of Renewable Energy (SCORE) framework for hydropower development both entailed more upfront cost in the provision of electricity and harmed biodiversity for critical species native to the river basin in Sabah and Sarawak (Shirley et al., 2015). Moreover, over the past few decades, electricity resources in Myanmar and ASEAN have become less diverse and more reliant on hydropower, which is susceptible to security risks, as well as human and ecological damage to critical fisheries (Tongsopit et al., 2015). Plans developed by international development partners have not fully explored the opportunity of developing solar, wind, and biomass electricity projects that have gained technological learning and experienced significant cost reductions during the past four years.

Planning a national energy system from the ground up offers the opportunity to make strategic decisions regarding the development of an energy generation portfolio. Strategic decision-making should aim to balance economic objectives (energy cost and availability) with environmental objectives on multiple levels, from local to global. This could improve rural livelihoods, enhance the reliability of the overall power system, and enable broader access to clean electricity.

Compared to the common *site-by-site, ad-hoc* planning and development process, the strategic planning and trade-off analyses of dams' impacts and benefits can bring about dam portfolios with significantly lesser conflict between hydroelectricity use and dam sediment trapping (and other potential impacts) (Opperman et al., 2015; Schmitt et al., 2018). When expanding hydropower, a strategic trade-off analysis can clarify the sequence in which dams should be built to result in no-regret dam portfolios. It can also identify dam sites with the worst impact, and thus have to be removed from consideration, and a limit for 'sustainable' dam development in a basin (Schmitt et al., 2018). This type of analysis can be incorporated with power system optimisation planning to evaluate the cost of an alternative future in energy.

Energy system planning frameworks can point out cost-effective and low-carbon pathways in the expansion of a country's electricity production using different sources of electricity (Kittner et al., 2016). Such frameworks can inform decision makers about site selection and timing of future hydropower development from an economic and carbon emission perspective, but not from the perspective of the impact on river systems.

The Asian Development Bank (ADB) and other multilateral development banks have found a significant potential for renewable energy development in Myanmar, yet have many of their efforts centred on securing adequate hydropower capacity (ADB, 2015).

As an alternative, a few studies have aimed to understand the hydropower development plans from a regional perspective, incorporating surplus electricity trade into a least cost model. Such studies sought to understand what the true alternative energy costs are that will meet the projected power demand growth and provide electricity access nationwide. In Lao PDR and other countries along the Mekong, for instance, recent studies have found that exporting utility-scale renewable energy such as solar and wind power could provide more reliable and secure export revenues than would hydropower, which is susceptible to changing flows and river conditions due to climate change (Avila et al., forthcoming).

This research builds on a framework designed to optimise dam portfolios for minimal sediment trapping. Sediment trapping is the major cause of fish, land, and livelihood losses as a result of hydropower development. For example, the Mekong River has experienced the effect of sediment trapping due to decades of hydropower development.

Our research framework consists of estimates of sediment yield from various parts of the basin, a simplified sediment routing model with a component for reservoir sediment trapping, and a multi-objective evolutionary algorithm.¹ Dam portfolios consist of dam sites that are identified as candidates for development in the basin area (Open Development Mekong, 2014). That framework is then coupled with another framework for evaluating strategies that aim to meet Myanmar's electricity demand through different mixes of energy sources (Kittner, Dimco, et al., 2016).

¹ See Garzanti et al. (2016), Kondolf et al. (2014), Schmitt et al. (2018), Hadka and Reed (2012).

The framework could be used to find optimal trade-offs amongst different objectives:

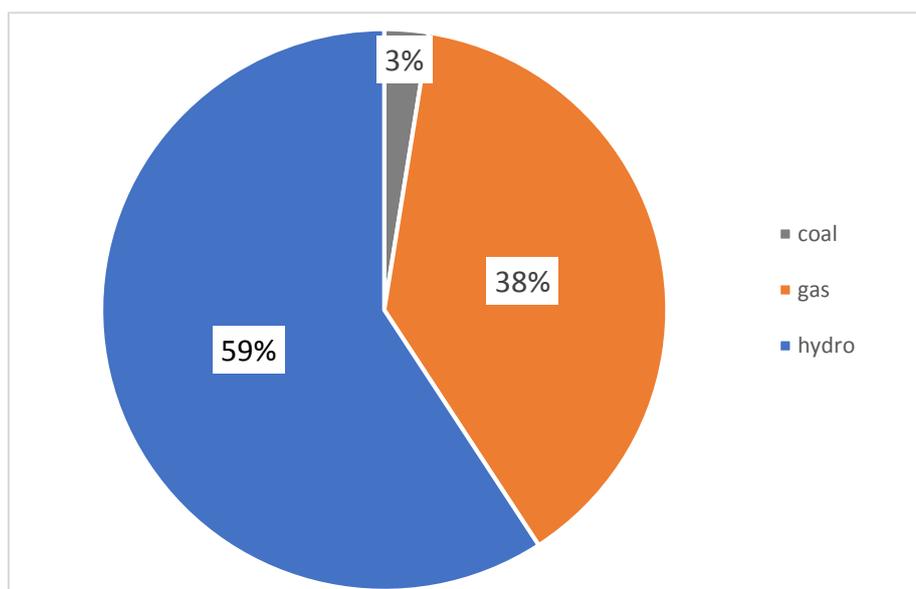
- 1) Total energy production coming from hydropower
- 2) Levelised cost of total electricity production from future portfolios [\$/kWh]
- 3) Reduction in sediment load in the Irrawaddy [t/yr]
- 4) Reduction in sediment load in the Salween [t/yr]

Reducing the sediment load from the Irrawaddy and Salween river basins is challenging because the total amount of sediments in each of these rivers depends not only on Myanmar's dam development decisions, but also on the amount of dam construction in the upstream parts of these rivers in China.

3.2 Energy Modelling Scenarios

Figure 3-1 shows Myanmar's installed electricity generation mix by generation type. Hydropower currently provides the largest source of electricity generation, with natural gas and coal-fired power stations comprising the remainder. There are still ample opportunities to diversify the electricity sector.

Figure 3-1. Current Installed Power Generation Mix in Myanmar by Generation Type



Source: ADB (2016).

A holistic approach to analysing the least cost development in the power sector helps target those countries that could also pursue alternative investment plans in the energy sector to promote financial and environmental sustainability.

The energy modelling tool employed here not only allows energy system experts to evaluate the costs, benefits, and impacts of different projects; it also facilitates a dialogue with policymakers in other areas as well as with the public over the need for, and costs and impacts of, different energy pathways and strategies. No model is perfect, and all are limited by available data, but the use of a clear, open-access model is vital in making all interested parties understand the impact of individual projects and larger development objectives.

The Excel-based model determines the optimal generation portfolio based on the inputs on the energy resource potential of the region, existing installed capacity, average capacity factors, and peak contributions. It identifies discrete annual investment decisions by finding the least-cost generation capacity additions needed to meet annual load and peak demand. The least-cost generation mix is determined using a linear optimisation:

$$\min_c NPV(C_i)$$

Where the Total Generation Cost $C_i = \text{Capital Cost} * \text{Capacity} + \text{Variable Cost} * \text{Generation}$ while Capital Cost is expressed in \$/MW, Capacity in MW, Variable Cost in \$/MWh, and Generation is expressed in MWh. Capacity (MW) is the decision variable of the linear programme.

Table 3-2 summarises the system parameters and scenarios developed in comparison with the JICA model (JICA, 2014).

Table 3-1. System Parameters and Scenario Summary Compared to the JICA Model

Scenario	Notes	Estimated Capital Cost Expenditure	Reference Figure
JICA Masterplan	Follows guidelines and assumptions developed in the 2014 JICA Power Development Plan. In the original study, renewables are treated exogenously; we add renewables into the assumption mix and optimise endogenously.	US\$11.7 billion	Figure 3-2
Low-cost distributed energy resources	Follows current technology innovation and learning for renewable energy resources including solar PV, small-scale hydropower, wind, and energy storage facilities	US\$8.1 billion	Figure 3-3
ASEAN Power Grid (APG) Participation	Follows current technology innovation and learning while participating in an expanded power trade market for electricity imports and exports; APG includes 15 priority interconnection projects identified at the ASEAN level	US\$8.4 billion	Figure 3-4

JICA = Japan International Cooperation Agency; PV = photovoltaic.

Source: Authors.

Table 3-2. Technology and Capital Cost Assumptions Compared with Business-As-Usual Scenario

Technology	Lifetime (Years)	Initial Capital Cost (\$2012/kW)	Capital Cost AGR (%)	Initial Fixed O&M Cost (\$2012/kW/yr)	Fixed O&M AGR (%)	Initial Variable O&M Cost (\$2012/MWh)	Variable O&M AGR (%)
Photovoltaic	20	1,100	-1.93%	25	-0.52%	0	0.00%
Wind	25	1,500	-0.35%	39	-0.37%	0	0.00%
Biomass	30	2,200	-0.27%	74	-0.27%	0	0.00%
Small-hydro	40	2,400	0.09%	59	0.09%	0	0.00%
Large-hydro	50	1,940	0.47%	47	0.44%	0	0.00%
Coal	40	1,200	0.00%	40	0.00%	4.47	0.00%
Natural Gas	30	900	0.00%	20	0.00%	3.6	0.00%
Diesel	20	371	0.00%	3	0.00%	13.88	0.00%

O&M = Operation and Maintenance; AGR = Annual Growth Rate.

Source: Authors.

Table 3-3. Variation of Capacity Factors, Both Real and Observed for Myanmar Based on Existing Literature

Resource	Capacity Factor	Reference
Gas	70%	(Nam, Cham, and Halili, 2015)
Coal	45%	(Nam et al., 2015) (World Wildlife Fund, 2016)
Hydro	40%	(Fairhurst, 2016)
photovoltaic	15.4%	(Siala and Stich, 2016)

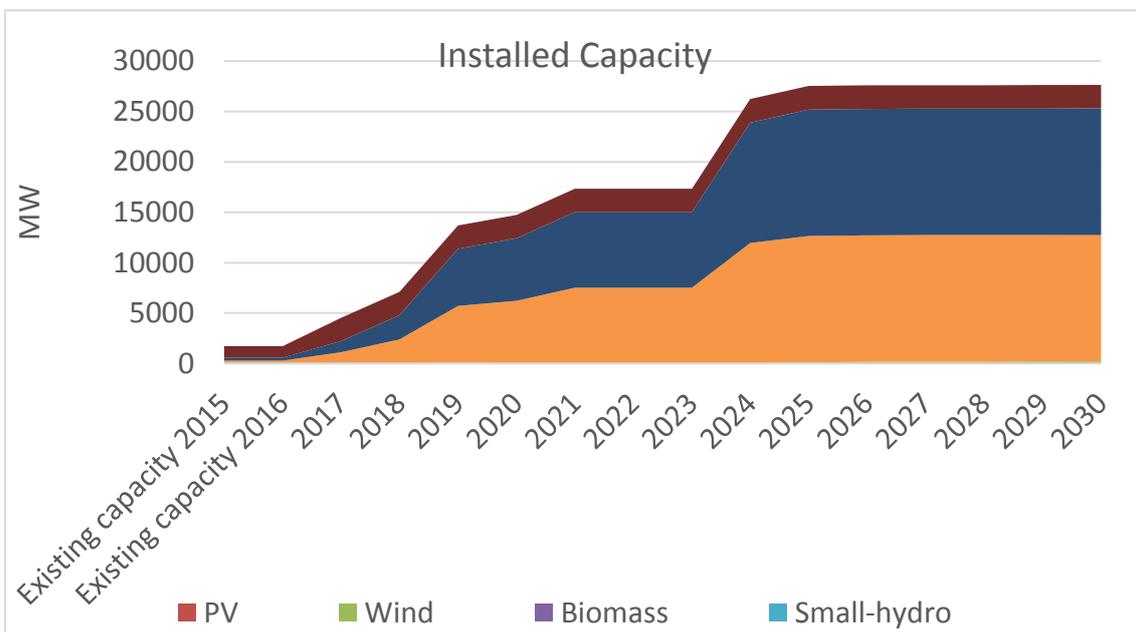
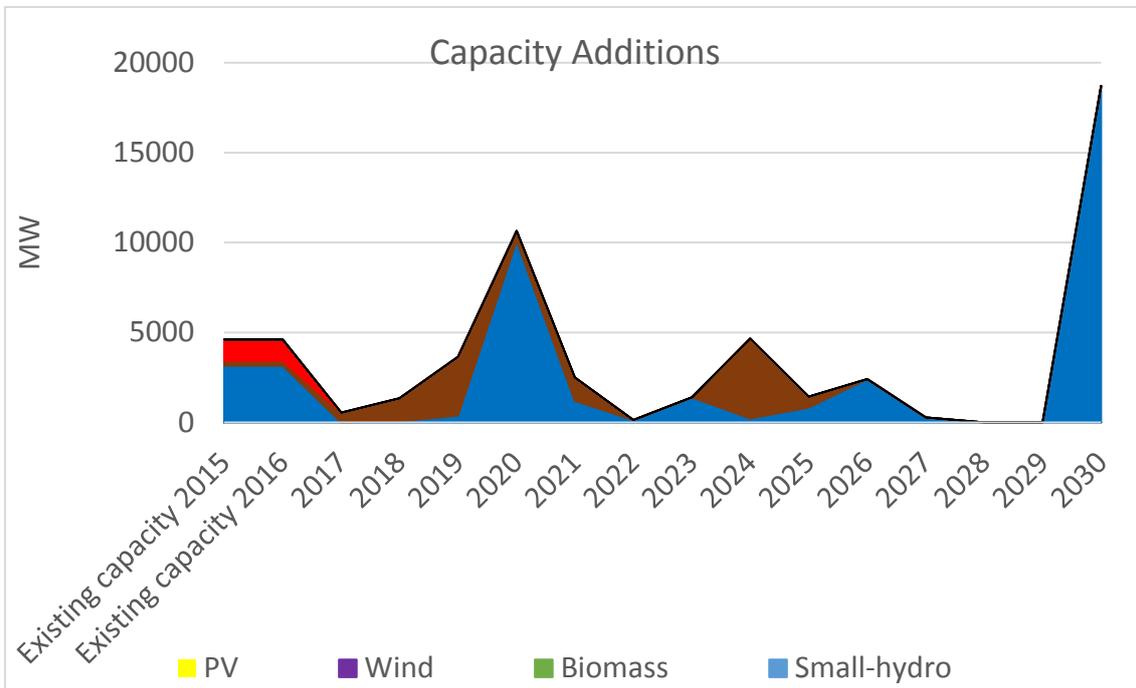
Source: Authors.

The study's scenarios based on the parameters and inputs in Table 3-2 and Table 3-3 are then compared with the proposed JICA power development plan to consider alternatives that can meet the power demand and export projections. Findings show that the low-cost solar and ASEAN power grid participation scenarios can generate reliable electricity at lower cost than some of the proposed large-scale hydropower projects that are under discussion (see Table 3-2). The model description can be found in Appendix 2 with full details on the inputs, outputs, and assumptions.

The hydropower dam portfolios are then compared within the different least-cost generation mixes presented in Figures 3-2 to 3-4 in a spatially and temporally explicit model. The model determines the optimal construction sequence of proposed hydropower portfolios to minimise environmental risk and reduce sediment trapping in rivers.

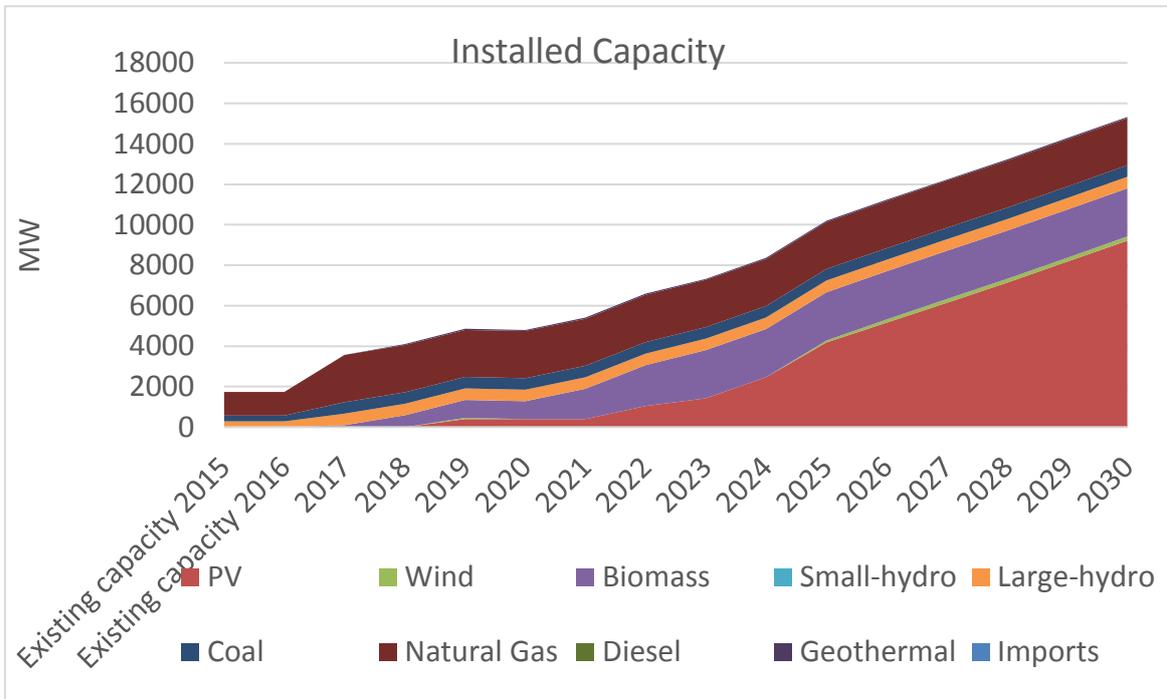
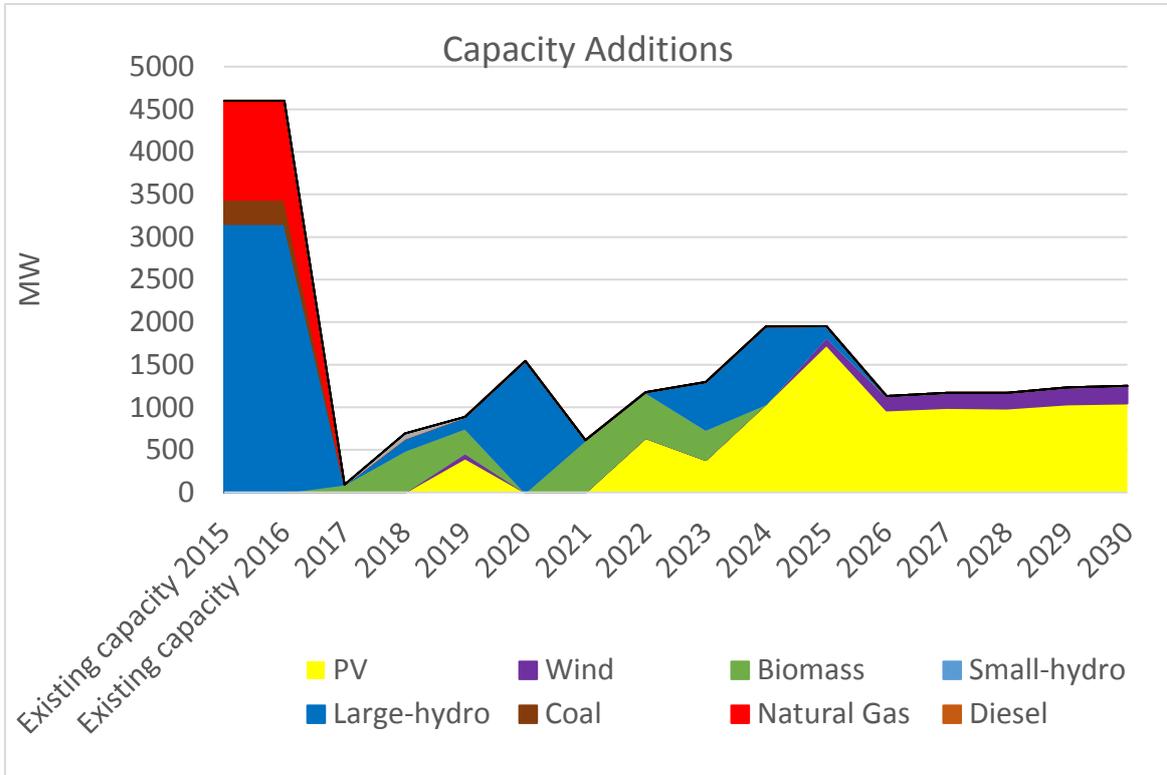
The model accounts for the non-dispatchability of some renewable energy sources using a peak load contribution factor, where wind and solar have less than a 10% contribution to peak demand. The model does not have high spatial and temporal resolution – a trade-off for the robust analysis without large data requirements that would be prohibitive in some regions. It also allows for quick sensitivity analysis by duplicating the model for varying scenarios, such as cost overruns and carbon prices. The model here underestimates the full dispatchability of solar and wind resources. But this could change due to the rapidly falling cost of storage resources that would facilitate integrated solar and wind systems to respond to grid operator controls within seconds to minutes (Kittner et al., 2017). It also follows on previous least-cost geospatial analyses of Myanmar's grid electrification effort (Modi et al., 2014), with a focus on larger-scale infrastructure investments.

Figure 3-2. Planned Business as Usual Capacity Expansion Based on JICA Scenarios



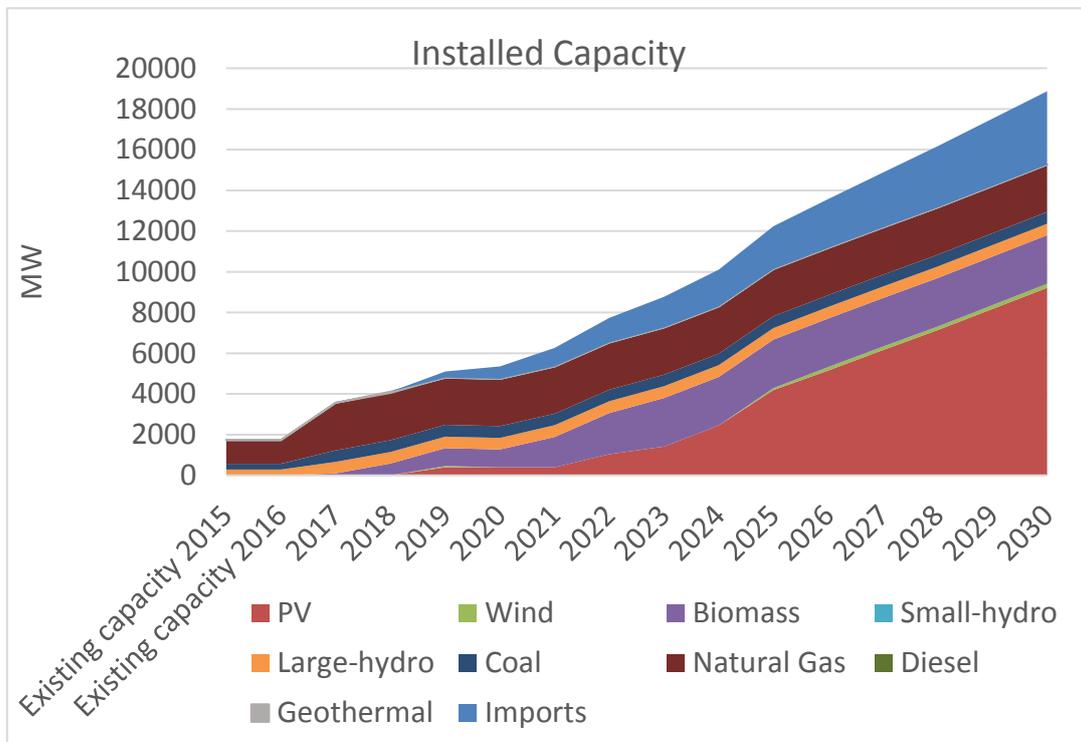
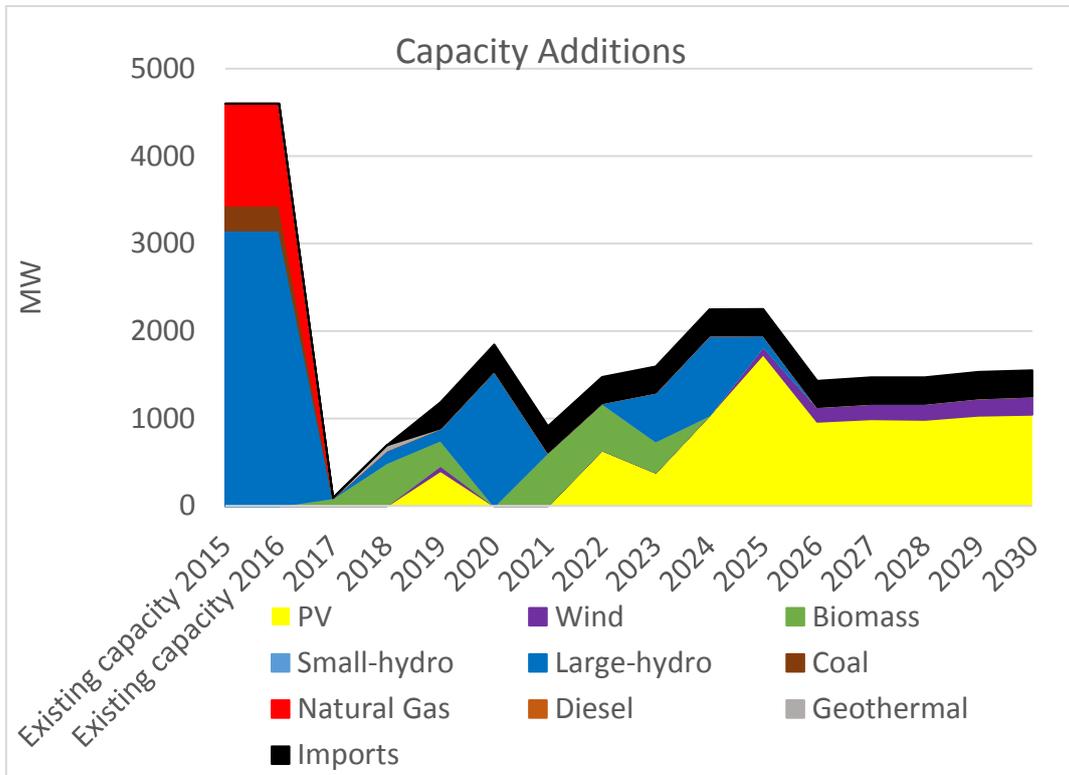
Source: Authors.

Figure 3-3. Low-cost Solar Capacity Expansion Case



Source: Authors.

Figure 3-4. ASEAN Power Grid Participation Capacity Expansion Pathway



MW = megawatt.

Source: Authors.

The optimisation process considers all candidate dam sites in Myanmar to find optimal dam portfolios. Dams that are already commissioned are included in all portfolios. Those in China are outside the spatial scope of this analysis, but could be easily included in a next step.

‘Sustainable’ hydropower in the country is then defined here as hydropower that does not trap more than 50% of the total incoming sediment in both rivers, and not more than 50% of the sediment in either river.² Both the Salween and Irrawaddy rivers have a hydroelectric potential of around 70 GW. Fully developing that potential would result in trapping around 60% and 70% of the total incoming sediment, respectively. Such would impact the sediment budget of the Salween river much more (< 90%) than that of the Irrawaddy river (<60%).

For portfolios that do not trap more than 50% of sediments in either river, there is a clear break point; that is, a limit for sustainable hydropower. Developing portfolios with more than 150,000 GWh/yr of hydropower production would lead to disproportional sediment trapping. Hence, it is proposed in this study that such production value be the limit for sustainable hydropower production.

It should be noted that this break point is not evident when considering all pareto-optimal portfolios, which follow a nearly linear trade-off between hydropower production and sediment production. However, pareto-optimal portfolios with high production would require trapping most of the sediment in the Salween river and are therefore not considered sustainable.

3.3 Discussion and Policy Recommendations

The proposed JICA pathway would incur higher direct costs to investors even before one starts considering the ecological impact of river ecosystems in the Irrawaddy and Salween basins. Furthermore, by identifying opportunities where solar, wind, and biomass generation are less expensive than large-scale hydro-power, the analysis highlights the fact that there are lower-cost options that can meet the same amount of electricity demand for in-country use and export without trapping large quantities of sediments. Therefore, this study (i) proposes an alternative sequencing to hydropower development that sustains the country’s electricity supply and

² It can be debated if this is a good strategy or if one should allow for ‘sacrificing’ one river. However, that will also depend on the results of the energy model.

economic development; and (ii) identifies the most problematic hydropower dam sites that could instead benefit from solar, natural gas, biomass, and small-hydro substitution as electricity generation technologies.

Contrary to the JICA report, this study finds that when including realistic assumptions for alternative energy resources, results will show that future capacity expansion *can* utilise more solar photovoltaic than hydropower on a least-cost development basis. The use of solar photovoltaics becomes possible due to (i) its falling costs; and (ii) the potential for distributed energy resources to leapfrog centralised utility-scale fossil plants.

The authors of this study now plans to identify those dams that are not cost-optimal as well as contribute to the greatest amount of sediment trapping. Moreover, they are already identifying the most damaging hydropower plants that are in the pipeline and finding alternative sources that can meet the future electricity demand of the country.

Based on the modelling results, the next step for this study team is to consult with relevant government agencies so as to understand the viability of different scenarios, including the design of alternatives, and draw up the resulting recommendations. Beyond simply evaluating the investment characteristics, each scenario should include future stakeholder consultations on the feasibility of a smooth transition. Future positions on hydropower plans and large-scale energy investment are critical in understanding the energy transition in Myanmar.

Further study is necessary to implement the cost sensitivities into the optimisation framework. Additionally, there is a need to decide how to incorporate some of the distributed energy resources, including solar-based mini-grids and existing mini-hydropower plants that are in operation, but lack grid connections.

Small-scale hydropower complements solar power well, and local businesses in rural areas could do well to scale by attracting capital investment in areas where local small-scale hydropower installations have been operating for decades.

Finally, the research team acknowledges that the investment community needs to be considered, whether that be to pay closer attention to increased investment from Singapore relative to China or to understand the controversy and ongoing discussions on the Myitsone power plant within the National League for Democracy (Kittner and Yamaguchi, 2017).

The modelling results highlight that under a least-cost framework, distributed energy resources contribute as electricity generation options and are built before investing in large-scale hydropower and thermal projects. This has significant implications on power sector planning and implies that the high penalty cost of transmission for large-scale projects may face future cost overruns. Investors that are interested in promoting sustainable energy options in Myanmar have significant options available and solar resources to use at low cost.

Furthermore, if concomitant investment in regional transmission interconnections are made (thus expanding the viability for affordable imports and power trade), Myanmar can take advantage of electricity surplus from Thailand, Lao PDR, and China, and trade electricity in an integrated ASEAN market. This could lower the levelised cost of electricity compared to the business-as-usual case by 31%. Such significant cost savings justify the promotion of regional coordination and cross-border independent power producer agreements. Even if transmission interconnection projects falter and face higher costs, the second scenario in this study – which investigates the role of distributed solar power – shows cost savings of 20% relative to the base case scenario. The second scenario also eliminates future investment in thermal generation, given that there is now an oversupply of existing generation and low-cost availability of small-, medium-, and large-scale PV resources.

To summarise, there are three key takeaways from the energy pathways modelled here:

- The amount of hydropower needed is a function of different expansion strategies for renewables in the basin and can be significantly reduced when alternative options are considered.
- The base case would require nearly four times more hydropower capacity than a solar-based alternative that meets similar energy demands. This allows for minimal river and human impacts on resettlement.
- Either utilising low-cost solar power or participating in the ASEAN power grid would yield better economic and environmental performance compared to the business-as-usual pathway based on initial capital cost, levelised cost of electricity, and combined sediment trapping/river fragmentation between the Salween and Irrawaddy river basins.

As foreign direct investment targets Myanmar in its next wave of Green Climate Funding and other development-based finance, investors should take note that projected returns on

hydropower and thermal investments may lead to future stranded assets. The emergent role of decentralised energy options would allow investors to improve the climate and public health by replacing expensive diesel generators, and simultaneously offering a viable alternative (Alstone et al., 2015). The abundant, low-cost availability of solar and wind power, and options to balance loads with transmission interconnections in a regional power grid undercut the cost of planned large-scale plants, making a significant economic argument for distributed energy.

Previous national electrification plans that treat solar and mini-hydropower as purely off-grid options should be revisited and updated. This time, the plans should reconsider their ability to provide flexible grid-scale resources both as rural electrification options and as alternatives to the large-scale hydropower dams that have been ecologically damaging.

Chapter 4

SWOT Analysis of Utility-Scale Solar Energy in Myanmar

Endowed with one of the best solar resources in the region, Myanmar can profit from more intensive use of solar energy. Although solar energy is increasingly being advocated, little progress has been achieved. To provide insights into the strategic planning on energy currently being undertaken, the authors conducted a SWOT analysis of utility-scale solar energy in Myanmar. Its development data were collected from a variety of sources including academic and grey literature as well as informal conversations with relevant stakeholders.

Although the main objective here is to diagnose the development of utility-scale solar power generation in Myanmar, this SWOT analysis also provides some important insights that can be used as takeoff points for further discussion amongst experts. First, utility-scale solar energy is proven to bring several strengths to the country's power sector. The photovoltaic technical potential is located in the Central Dry Zone, which is relatively flat and close to the national grid, facilitating the installation of the solar panels and the interconnection to the grid.

Second, the combination of utility-scale solar energy and increasing regional energy trade is an opportunity for Myanmar to export clean energy to neighbouring countries, given that the nation is part of several regional initiatives such as the Greater Mekong Subregion, ASEAN Power Grid, and South Asia Subregional Economic Cooperation. Lao PDR has for long positioned itself as 'the battery of Southeast Asia'; Myanmar can likewise position itself as a champion of solar energy in the region.

Third, there is a need for a transparent policy framework to streamline investments. Although a limited number of utility-scale projects have been signed, there is a lag in the implementation phase. Specifically, none of the projects has been finalised yet.

Finally, it is noted that the solar energy initiatives in Myanmar have been directed only to rural areas. Expanding this focus to the national grid should be the next viable step.

4.1 Introduction: Policy Framework to Support Renewable Energy Generation in Myanmar

Myanmar has one of the lowest levels of energy access to energy in the world – lower even than its neighbouring countries. As mentioned in Chapter 2, Myanmar is currently working to attain a universally sustainable electricity access by 2030. This puts Myanmar in a bind with regard choosing its generation technologies. It is hoped that the country will avoid a carbon lock-in pathway by developing and implementing policies that support the deployment of low-carbon technologies.

A previous study (Del Barrio and Sugiyama, 2018) found that Myanmar’s plans currently underestimate the potential of solar energy. In particular, while there has been an apparent shift towards solar-based solutions for off-grid electrification, utility-scale solar development has yet to be mainstreamed. Current guiding policy documents prepared by the government have downplayed the potential role of renewables such as solar energy.

This situation in Myanmar is counter to the global trend where there are decreasing prices and faster deployment of solar PV systems. Furthermore, the above-mentioned weaknesses in Myanmar’s plans do not help existing conditions that already favour more intensive use of solar energy to thrive. The country’s Central Dry Zone has the solar potential that would allow it to be connected to the national grid, thus avoiding the cost – in time and money – of having to develop large transmission lines.

4.2 A SWOT Analysis of Utility-Scale Solar Energy in Myanmar

Using the Del Barrio and Sugiyama (2018) findings as its reference, the study team aimed to identify the drivers of and barriers to the development of utility-scale solar generation infrastructure in Myanmar.

To take advantage of its existing potential, Myanmar needs to develop a strategic plan for utility-scale solar facilities. A participatory process will be required to catalyse the discussion amongst stakeholders. Terrados et al. (2007) list a five-phased process for the development of a strategic plan: (i) preliminary phase; (ii) diagnosis and initial reports elaboration phase; (iii) collective participation phase; (iv) synthesis phase; and (v) plan approval phase.

Since a diagnosis of the state of utility-scale solar facilities in Myanmar is still lacking, this study undertook a SWOT analysis.

Through the SWOT analysis, this chapter looks at utility-scale solar energy as a strategic alternative for Myanmar's present and future energy needs. In that sense, this chapter contributes to the ongoing discussion on the power generation capacity's expansion plans.

The SWOT analysis originated in the business field as a tool for strategic analysis and planning (Pickton and Wright, 1998). It has the ability to 'yield useful information about the future viability of the considered system' (Paliwal, 2006). Its application has extended to numerous other fields (Terrados, Almonacid, and Hontoria, 2007).

Notably, SWOT analysis is widely applied in the energy sector. Chen et al. (2014) applied SWOT to examine renewable energy policies in three East Asian economies: Republic of Korea, Japan, and Taiwan. Lupu et al. (2016) conducted a SWOT analysis of solar energy resource in Romania and identified key factors for its development. The European Commission (2005) ran a project that used a SWOT analysis to compare Europe, the United States, and Japan and identified the most important gaps in research in different energy technologies. The World Bank, too, briefly introduced a SWOT analysis for solar resources in Myanmar (Suri et al., 2017). Shi (2016) employed a SWOT analysis to highlight the possibility for ASEAN to move from a fossil fuel-dominated energy mix towards a green energy strategy, as advocated by the ASEAN's regional vision and action plan. Greacen (2015) applied SWOT to evaluate the options and consequences of further deployment of mini-grids in Myanmar.

The Asian Development Bank has used a SWOT analysis for Myanmar's food crops, water resources, and environmental subsectors (ADB, 2013).

SWOT analysis is usually presented in the form of a 2 x 2 chart, is divided into four categories (Start and Hovland, 2004), as shown in Table 4-1. Strengths and weaknesses are internal factors; opportunities and threats result from the external environment or external forces (Paliwal, 2006).

Table 4-1. SWOT Framework

Strengths Internal + Helpful	Weaknesses Internal + Harmful
Opportunities External + Helpful	Threats External + Harmful

SWOT = Strengths, weaknesses, opportunities, and threats.

Source: Created by the authors.

Different approaches in undertaking a SWOT analysis can be found in literatures. Some studies have obtained information from experts through such collective exercises as seminars (Markovska, Taseska, and Pop–Jordanov, 2009; Terrados et al., 2007) or through surveys (European Commission, 2005). However, most investigations have based their analyses on a review of the existing literature (Chen et al., 2014; Soimu, 2014).

As an initial approximation, this chapter draws from existing literature (academic, journalistic, and official reports) and from information collected through discussions with local and international experts during visits, workshops, and seminars held and attended by the research group.

This chapter first provides an overview of the lack of inclusion of solar energy in current guiding policy documents and discusses the related drivers and impediments. Then, the SWOT analysis is presented, further analysing each factor. Finally, this chapter discusses the results and policy recommendations.

4.3 Solar Energy in Myanmar’s Power Sector Plans

Starting 2011, reforms towards the democratisation of Myanmar opened the door for the nation’s rapid re-engagement with the international community. President Obama ended the United States’ economic sanctions in 2016 (Exec. Order No 13742 v.81 no.197 p.70593, 2016). The European Union has also lifted its sanctions, although an arms embargo remains in place (Council of the European Union, 2013). Following the United States and European Union’s lifting of sanctions, Myanmar re-engaged in cooperation programmes with development partners such as Japan International Cooperation Agency (JICA), ADB, World Bank, the German Corporation for

International Cooperation (GIZ), and the Norwegian Agency for Development. Local and international nongovernmental organisations are also involved in Myanmar’s energy sector.

The current National Electrification Plan and the National Electricity Master Plan (NEMP), which were developed with support from the World Bank and JICA, respectively, do not assign an ambitious role for renewables. The National Electrification Plan (NEP) recognises diesel mini-grids only, leaving solar energy as a solution at the individual household level (Castalia Strategic advisors, 2014). The NEMP, meanwhile, caps the penetration of renewables at 10% by 2030 (JICA, 2015). There are alternative studies, however, that have examined the possibility as well as seen the merits of raising the targets for the penetration of renewables in Myanmar (Denruyter, 2016; Kean, 2017). Table 4-2 compares the power generation mixes estimated by the official plan (i.e., JICA’s) and one alternative plan proposed by the World Wildlife Fund. The large discrepancy in the figures of the two plans suggests that it is necessary to update capacity expansion plans without externally constraining renewables (Del Barrio–Alvarez and Sugiyama, 2018).

Table 4-2. Installed Capacity Under Official and Alternative Scenarios by 2030 (MW)

Resource	Japan International Cooperation Agency *	World Wildlife Fund **
Coal	7,940	0
Natural gas	4,758	1,774
Hydro (all sizes)	12,350	7,413
Other renewables	2,000	8,959 solar 5,149 onshore wind 1,250 biomass

* The proposed power resources balance scenario is presented in this table.

** The most conservative of the scenarios proposed (the Sustainable Energy Scenario) is presented in this table.

Source: (Denruyter, 2016; Japan International Cooperation Agency, 2015)

The 10% cap on renewables is currently being reconsidered. An ongoing study funded by the United States (US) Trade and Development Agency is examining the grid impact of three different scenarios of integration of variable renewables (Depierreux, Shumway, and Sparavier, 2017). The first scenario is based on thermal plants; the second and third scenarios estimate a 10% and 19% renewables penetrations, as a percentage of peak demand. The study's target year is 2020, including the transmission system considered by Myanmar's Ministry of Energy and Electricity (MOEE). Results show that even the most ambitious scenario is possible without any negative impact on the reliability of the system.

4.4 Drivers of and Barriers to Implementing Solar Energy in Myanmar

While there seems to be a low interest in solar energy amongst government officials, the large potential of solar energy and the growing electricity needs of Myanmar have captured the attention of private sector investors.

The MOEE has presented its plans for 1.5 GW utility-scale pipeline solar power plants, which are in different stages of development (Beetz, 2018; Oo, 2017). Table 4-3 summarises the planned projects, based on the scant information available.

However, the progress of these projects was slow. In 2014, the Thai firm Green Earth Power signed an agreement with the government to develop a 220-MW solar plant in Minbu (Magway region), which was reported as the most advanced utility-scale solar investment in Myanmar. The project was initially expected to complete its first phase in 2016 (Phyo, 2014). Information about its progress is scarce, and only 40 MW of the Minbu project is expected to be achieved by the first quarter of 2019 (Shumkov, 2018).

Appropriate policies are needed to address the discrepancy between the potential of utility-scale solar energy and investment interest, and actual progress. Vakulchuk et al. (2017) evaluates the attractiveness of the energy sector in Myanmar to investors based on a project jointly developed by the Myanmar Institute for Strategic and International Studies and the Norwegian Institute of International Affairs, and supported by the Ministry of Foreign Affairs of Norway.

Table 4-3. Utility-scale Solar Projects Under Development in Myanmar

Project / Location	Region	Installed Capacity	Developer	Current Status
Minbu	Magway	220 MW (170 MW?)*	Green Earth Power (Thailand)	MoU+PPA
Nobuai	Mandalay	150 MW	ACO Investment Group (USA)	MoU+PPA
Wandwin	Mandalay	150 MW	ACO Investment Group (USA)	MoU+PPA
Shwe Myo	Nay Pyi Taw	10 MW		MoU
Sagaing and Mandalay	Sagaing and Mandalay	880 MW (80 MW?)**		MoU
Thapaysan	Nay Pyi Taw	100 MW		MoU

MoU = memorandum of understanding; PPA = power purchase agreement.

* Initial information reports 220 MW (Phyo, 2014), more recent data mention 170 MW (Shumkov, 2018).

** No evidence exists about this project other than the official presentation by the MOEE. The media have reported another 80 MW project in the same region (Hammond, 2016), which may indicate potential errata in the official information.

Source: Adapted by the authors from Beetz, 2018; M. M. Kyaw, 2017; Oo, 2017; US Embassy, 2017.

The report includes a list of factors that lessen the attractiveness of renewables in Myanmar, including:

- No national target or legislation on renewable energy;
- No dedicated public agency regulating the sector;
- Lack of business associations;
- Subsidies for grid electricity generated from fossil fuels, which put off-grid renewables at a disadvantage;
- Access to suitable land;
- Mountainous terrain and protected areas as well as political instability in key areas;
- Underdeveloped grid system for large-scale production;

- Lack of data on the renewable energy resource potential;
- Limited infrastructure for technical support and maintenance;
- High installation cost of solar panels and wind turbines;
- Disintegrated biofuel production and supply markets;
- Lack of local specialists;
- No taxation system for renewables;
- Security risks in conflict-prone Kachin, Rakhine, and Shan states

4.5 SWOT Analysis of Utility-Scale Solar Energy in Myanmar

Table 4-4 summarises the result of the SWOT analysis of the utility-scale solar energy in Myanmar. Each quadrant in the table is discussed in detail in the following subsections.

Table 4-4. SWOT Analysis of Utility-Scale Solar Energy in Myanmar

<p>Strengths</p> <ul style="list-style-type: none"> • Available potential to be developed • Best resource areas located in flat areas near national grid • Public support for solar energy and opposition to coal and large-scale hydro • Shorter lead times of solar power plants in contrast with other technologies • Increasing experience on solar PV technologies through off-grid projects 	<p>Weaknesses</p> <ul style="list-style-type: none"> • Uncertainty regarding the establishment of an independent regulatory commission • Low electricity tariff requiring very low generation prices • No supporting policy for the deployment of renewables
<p>Opportunities</p> <ul style="list-style-type: none"> • Regional power trade • Seasonal complementarity with hydro • Decreasing global prices 	<p>Threats</p> <ul style="list-style-type: none"> • Potential land disputes • High levels of perceived corruption • Delays in the implementation of current projects

<ul style="list-style-type: none"> • International investment interest in Myanmar • Growing investment in solar energy • Support from international donors 	<ul style="list-style-type: none"> • Security and reputation concerns • Absence from national plans
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Source: Prepared by the authors based on secondary data.

4.5.1 Strengths

Available potential to be developed

Myanmar has amongst the highest potential for solar photovoltaic power potential in Southeast Asia. The country’s technical potential has been estimated at between 40 TWh/year (ADB, 2015) and 118.2 TWh/year (Siala and Stich, 2016). More than half of the country (about 60%) is suitable for solar electricity generation (Oxford Business Group, 2016). Figure 4-1 shows the photovoltaic power potential in Myanmar.

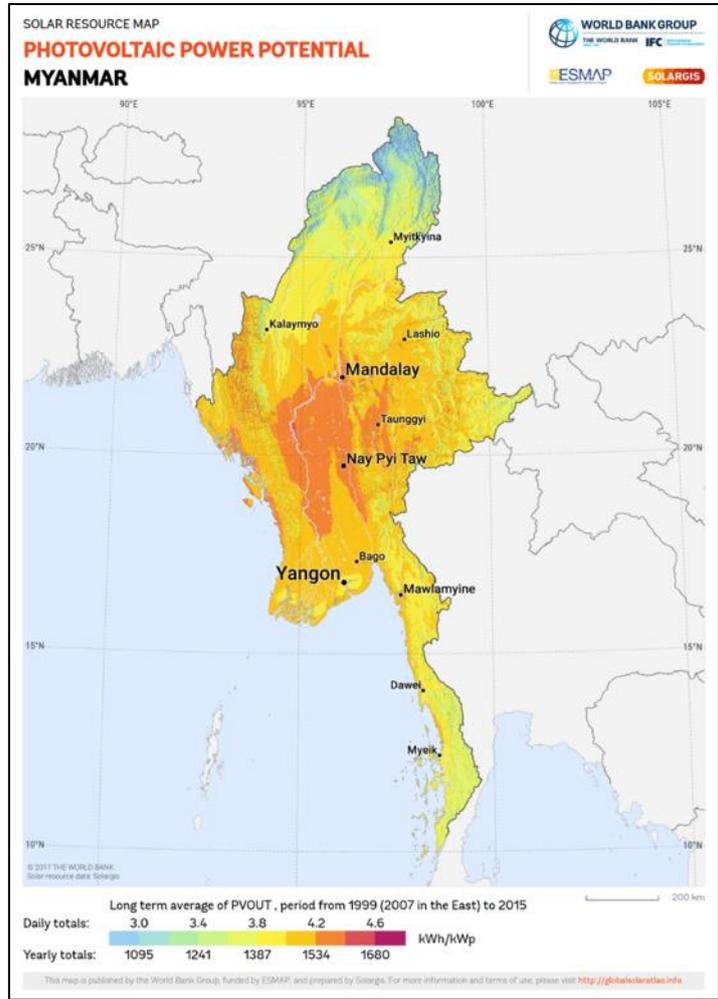
This potential remains mostly unexplored for grid-connected projects. With the exception of a couple of rooftop solar PV installations in the Junction commercial complex in Yangon and in a garment factory (Balch, 2016; Djordjevic, 2017), no utility-scale or commercial solar plants have yet been finalised. The fate of most planned projects remains unclear.

Against this background, the alternative scenario proposed by the World Wildlife Fund considers almost 9,000 MW by 2020; and 27,459 MW of solar PV systems and 4,800 MW of concentrated solar energy by 2050. That would make solar energy the dominant energy source in Myanmar’s generation mix by the mid-century (Denruyter, 2016).

Best resource area is located in a flat area and near the national grid

The main area of interest for utility-scale solar generation in Myanmar is the Central Dry Zone, a flat plain (Kyj, 2016) whose potential remains undeveloped. Figures 4-1 and 4-2 show the PV power potential in the country and how the areas of highest potential are located in flat areas.

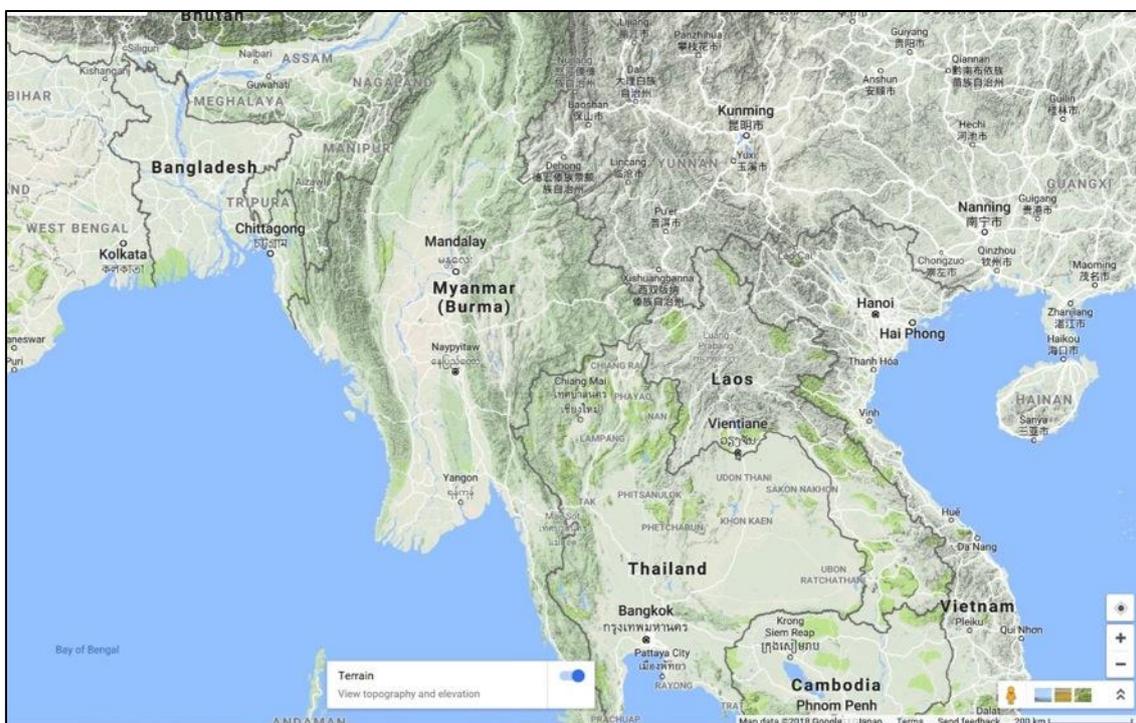
Figure 4-1. Photovoltaic Power Potential in Myanmar



Source: © 2017 The World Bank; solar resource data: Solargis.

The Central Dry Zone is composed of infertile soils (ADB, 2013), reducing concerns about conflicting uses of the land. Furthermore, the Central Dry Zone is mostly near the national grid, facilitating the connection of new power plants. To conduct the power generated by dams in the north, the national transmission system in Myanmar runs from north to south. With only one 500 kV line being built with bilateral support, the grid currently comprises a network of 230 kV, 132kV, and 66kV transmission lines (ADB, 2016).

Figure 4-2. Elevation Map of Myanmar



Source: Google Maps.

Public support

Solar energy enjoys public support as a viable alternative to coal-fired plants. Coal-fired generation is the subject of severe criticisms. Currently, there is only one coal-fired power plant in Myanmar, and the NEMP anticipates the opening of more coal-fired plants. However, environmental organisations and other local and regional nongovernmental organisations had mobilised their campaign against such plan (Nyein, 2017b).

The Union government has reconsidered its position following its democratisation since 2011. Currently, 'all coal-fired projects are cancelled' (M. M. Kyaw, 2017). However, a dispute has emerged at the federal level. The Kayin regional government has supported the development of a 1,280-MW Hpa-An coal power plant. The Union government has criticised the move and taken measures against it. The dispute remains unresolved (Han, 2017, 2018; Nyein, 2017a; Yimou Lee, 2017).

Shorter lead-time

Electricity demand is growing rapidly in Myanmar, and it is expected to continue — at least in the near term. Therefore, securing greater power generation is an urgent need. In this context, the ability to deliver electricity rapidly after the approval of a project becomes an important consideration. In addressing short-term needs, the shorter lead time and lower construction risks of solar energy compared with other technologies are important factors (Sovacool, Gilbert, and Nugent, 2014).

Developing the other types of generation plants faces challenges that are specific to Myanmar. For instance, coal power has traditionally faced strong public opposition. Moreover, the current Union government has taken a position against coal power use. Because of these barriers, these projects would take longer to complete.

Hydropower is the traditionally preferred choice of the government. The available potential is great, but in the short term, hydropower involves complications that are difficult to address. From an environmental and river management perspective, the Ayeyarwady (Irrawaddy, which crosses the country from north to south and a large proportion of the population depends on it), and the Thanlwin (Salween) rivers do not have dams in their main streams. How the construction of their dams would affect these rivers has yet to be studied (IFC, 2018).

Chapter 3 of this report describes a study on the influence on sediments during different scenarios of dam building. From a national reconciliation viewpoint, tension has increased over proposals for large-scale hydropower dams in some areas; those proposals are opposed by the central government. Alternative strategies could avoid those problems (Kittner and Yamaguchi, 2017).

Government has shown a recent interest in liquified natural gas (LNG). The signing of power purchase agreements for LNG power plants has been a highlight in the recent power policy development. The plants are expected to start operations by 2020, although there are some concerns over future costs (Kean, 2018a, 2018b).

Increasing experience with solar PV technologies through off-grid projects

Myanmar is rapidly gaining experience with renewable energies through rural electrification programmes. Pilot projects have been and are being implemented by different organisations with support from development partners. More recently, extensive programmes have been examining the use of renewables for rural electrification. In particular, a large number of solar home systems have been implemented (Greacen, 2015). As mentioned in Chapter 2, the DRD's National Electrification Plan, which had the help of the World Bank, has supported the development of solar-based mini-grids through what is widely known as the 60/20/20 programme. Under this programme, the government provides a grant for 60% of the cost of the mini-grid, while the developer and the local community cover 20% each. Village Electrification Committees are established in each village. The programme is still in its initial years of operation, and its scalability is uncertain. No similar programmes have been proposed for the national grid.

4.5.2 Weaknesses

Uncertainty in the establishment of an independent regulatory commission

To attract the appropriate investments, there should be mechanisms in place to resolve potential conflicts and secure transparency in the regulatory process. Myanmar's power sector is under the control of the state-owned, vertically integrated utility Electric Power Generation Enterprise (EPGE), and has a partly private energy generation component consisting of independent power producers (ADB, 2016; OECD, 2014). The Electricity Law of 2014 replaced the previous legislation dating back 1954 and introduced some major changes. Decision-making became partly decentralised when state governments were allowed to approve off-grid projects smaller than 30 MW (Oxford Business Group, 2016; Ross, 2015). More importantly, the creation of a regulatory commission has been envisioned in the 2014 law. However, such commission has not yet been created as of this writing, and the prospect of having a working commission remains unclear.

Low electricity tariff

Electricity tariff is highly subsidised in Myanmar. It is the responsibility of the MOEE to develop its own power generation products or sign power purchase agreements with private developers.

In 2017–2018, the subsidy was about K378 billion (approximately US\$280 million) (Chern, 2017; Htwe, 2017a), and is expected to increase to K450 billion (US\$330 million) in 2018 (FMR Research and Advisory, 2018). Ever since the tariff increased in 2014, households pay around US\$0.03–US\$0.04/kWh; industrial consumers pay US\$0.05–US\$0.10 cents/kWh (ADB, 2016). Tables 4-5 and 4-6 summarise the electricity tariffs for residential, industrial and commercial consumers. The MOEE has indicated that it wishes to raise the tariffs (Khin, 2017; Lynn, 2017b), but is faced with public opposition.

Table 4-5. Electricity Tariff for On-Grid Residential Consumers

Consumer range	Kyats / kWh	US\$ cents / kWh
Up to 100 kWh/h	35	2.6
From 101 kWh to 200 kWh	40	2.9
From 201 kWh and above	50	3.6

kWh= kilowatt-hour.

Source: Anbumozhi and Tuan (2015).

1 US\$ = K1,370.71 (xe.com, 2017)

Table 4-6. Electricity Tariff for On-Grid Industrial and Commercial Consumers

Consumer Range	Kyats / kWh	US\$ cents / kWh
Up to 500 kWh	75	5.5
From 501 kWh to 10,000 kWh	100	7.3
From 10,001 kWh to 50,000 kWh	125	9.1
From 50,001 kWh to 200,000 kWh	150	10.9
From 201,000 kWh to 300,000 kWh	125	9.1
300,001 kWh and above	100	7.3

kWh= kilowatt-hour.

Source: Anbumozhi and Tuan (2015).

1 US\$ = K1,370.71 (xe.com, 2017).

No supporting policy

Myanmar has not adopted any specific policy to attract investments into renewable energy. The Regulatory Indicators for Sustainable Energy, developed by the Energy Sector Management Assistance Program of the World Bank, provide a global comparison of the energy situation in different countries. In sustainable energy, Myanmar offers only fiscal incentives in the form of reduced import taxes as well as reduced sales taxes and other taxes (World Bank, 2016b). Neighbouring countries have implemented more sophisticated instruments such as feed-in tariffs and renewable energy auctions (Tongsopit et al., 2017).

4.5.3 Opportunities

Regional power trade

Myanmar is located between India, China, and the rest of Southeast Asia (through Thailand and with a small border with Lao PDR). Interconnections could be developed in the near future so as Myanmar can import electricity from neighbouring Lao PDR (Billen, 2016) and Yunnan (China). India has also proposed some schemes for exporting electricity. Currently, the interconnection with Yunnan appears to be the most advanced.

In the long term, Myanmar could utilise these interconnections to export electricity as well. The World Wildlife Fund's alternative scenarios show a rapid, large increase in power generation for export to neighbouring countries in the Greater Mekong Subregion. In particular, it has been forecasted that Myanmar will be able to export 40,000 GWh to Thailand by 2040 (Denruyter, 2016).

Seasonal complementarity with hydropower

Hydropower accounts for around 60% of Myanmar's power supply, although the contribution from natural gas is increasing. Power generation capacity is sufficient during the rainy season but becomes restricted during the dry season.

The Energy Master Plan, which was developed with support from the ADB, identified good seasonal complementarity between hydropower and solar energy (Emmerton et al., 2015). Maximum solar irradiance occurs between January and May, which is the time of minimum

output for hydropower; the situation is reversed from July to November. During the dry season, when the power supply is restricted, solar energy can be tapped to mitigate the chances of frequent blackouts (Ross, 2015).

Decreasing global prices

The world has seen a 70% decrease in the price of new solar PV systems since 2010 (IEA, 2017c). Reasonable PV system prices are already at the level of US\$0.06–US\$0.08/kWh (Dobrotkova et al., 2018). However, the final prices of solar energy vary from country to country.

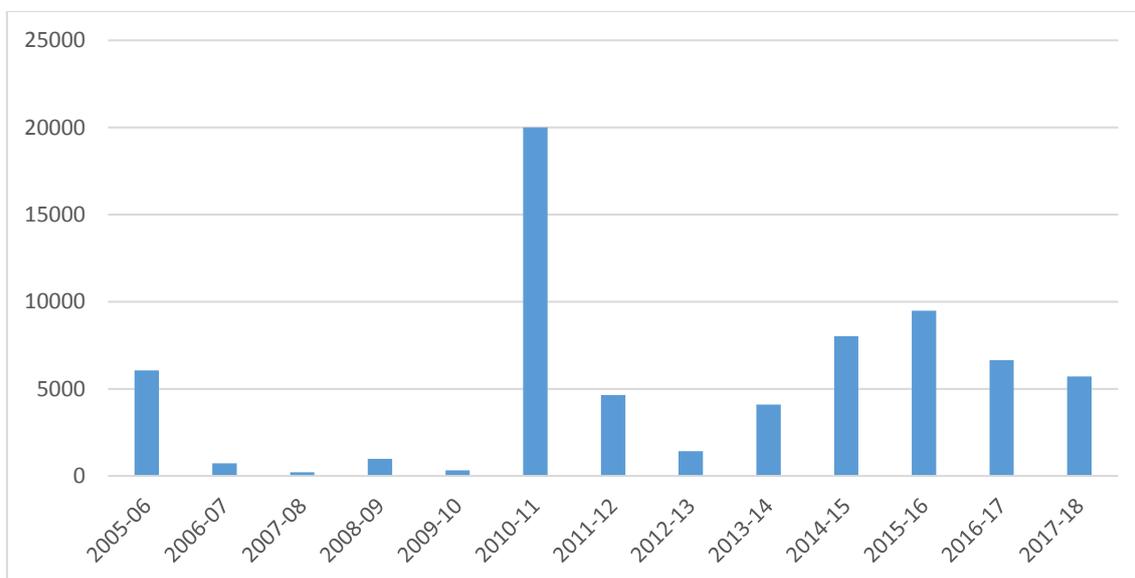
As Myanmar has had little experience in using solar energy, the initial actual prices could be higher in comparison with those in neighbouring countries. The outcome of policy innovations, such as the recent widespread application of energy auctions, is strongly dependent on several factors related to their design (Azuela et al., 2014; Del Río and Linares, 2014; Kruger and Eberhard, 2018; Mora et al., 2017).

International investment interest in Myanmar

In Myanmar, its democratic transition and opening up to the world have attracted the interest of many international investors and donor organisations. The lifting of economic sanctions by the United States and European Union has allowed investments to flow into Myanmar (Pun, 2016; Xu and Albert, 2016). Figure 4-3 shows the increase in investments compare to the previous decade.

In 2014, the Myanmar government announced the development of special economic zones. Since then, four special economic zones (SEZs) have been proposed: Thilawa, Fawei, Kyauk Phyu, and Sittwe (Khandelwal and Teachout, 2016). The Thilawa Special Economic Zone, supported by Japan, is the only one in operation; it had attracted about US\$700 million from over 70 companies by 2016 (Hunter et al., 2018). Considering the rising electricity demand linked to Myanmar's economic growth, the power sector itself can become another business opportunity for investors if a clear, transparent framework is developed (Matsui, 2017a).

Figure 4-3. Yearly Approved Amount of Foreign Investment in Myanmar (US\$ million)



Source: Myanmar Directorate of Investment and Company Administration (DICA).

Growing investment in solar energy

The cost reductions in technology, together with stronger efforts from governments, have also attracted large private investments in renewables, particularly solar PV systems. In 2017, solar energy became the fastest-growing source of power worldwide, with the global installed capacity increasing by 50% (IEA, 2017b). This development represents an important opportunity for Myanmar as a new market.

Support from international donors

Myanmar has been a recipient of loans and grants from multiple countries and multilateral institutions, particularly after its transition out of military rule. In addition to projects and programmes supported by JICA, the World Bank, and ADB, Myanmar receives help from the German Development Agency, Norwegian Agency for Development, and China. The Asian Infrastructure Investment Bank, the World Bank, and ADB are involved in the Myingyan gas-fired power plant project. Myanmar is part of the One-Belt, One-Road initiative, which includes building of gas and oil pipelines, and linking Kyauk Pyu Port in southwestern Myanmar with Yunnan Province in China. (Liu, Yamaguchi, and Yoshikawa, 2017).

4.5.4 Threats

Potential land disputes

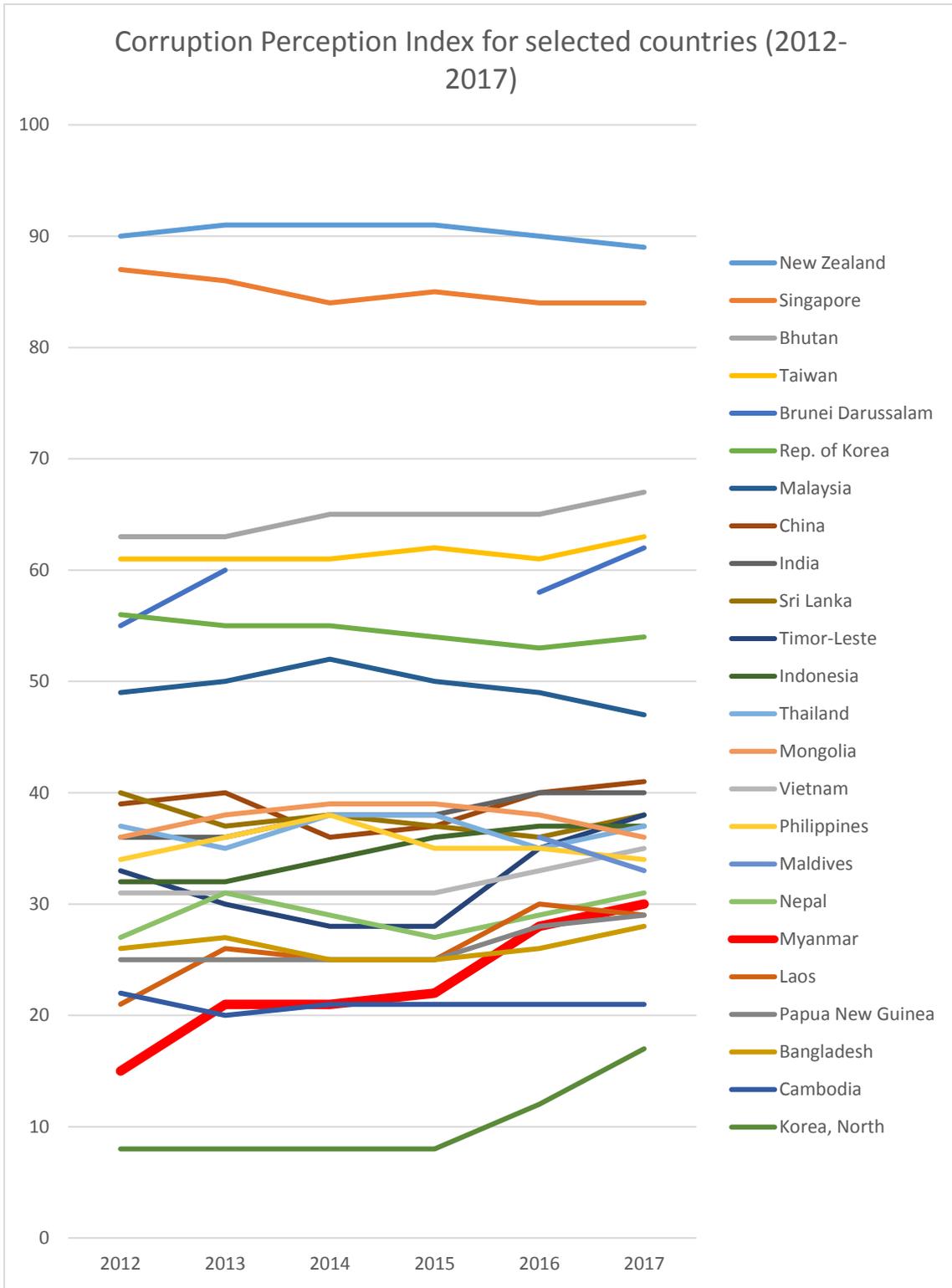
Utility-scale solar plants require vast areas of land, which may not be easy to obtain. The main challenges may come from securing the rights for such land. After decades of forced expropriations, many farmers in Myanmar are calling for the return of land ownership to them. Although the current government has expressed its intent to deal with this problem, little progress has been made (Barany, 2018; Myint, 2017b). The actions taken by the transitional government of Thein Sein may have had some negative consequences regarding the land-grabbing occurred during the years of military rule, such as the formalisation of the land-grabbing patterns and encouragement of land speculation (McCarthy, 2018). Today, the National Land Use Policy in Myanmar was adopted by the central government after an extensive consultation process (Oberndorf et al., 2017): This could represent an initial step in the long process of resolving the disputes.

High levels of perceived corruption

In Transparency International's Corruption Perception Index, the lower a country's ranking, the higher is its perceived corruption (Figure 4-4). In 2012–2017, Myanmar was ranked 130th out of 180 countries. Likewise, corruption is recognised as an obstacle for businesses (Ferrie, 2014).

An Anti-Corruption Law and Commission were established in 2013 and 2014, respectively, but had little impact (Soe, 2018). The NLD-led government has made the fight against rampant corruption a key objective, and improvement has been seen in recent years (Control Risks, 2017; Naing, 2017).

Figure 4-4. Corruption Perception Index for Selected Countries (2012–2017)



Source: Adapted from the Corruption Perception Index, Transparency International.

Delays in implementing currently approved projects

The lack of visible progress in already-agreed projects can dampen Myanmar's attractiveness to potential investors. As noted above, several utility-scale solar power plants are being developed. In particular, Green Earth Power (Minbu) and ACO Investment Group (Nobuai and Wandwin) have already signed MoUs and power purchase agreements with the government for three projects. Nevertheless, none of those projects has yet been finalised. Even the Minbu project, which was way ahead of the rest, has been hit by a long delay. Signed in 2014, the first phase of the Minbu project was expected to be operational in 2016 (Petrova, 2014), but such target has long changed. Currently, the project's rollout is expected to be by the end of 2018.

Security and reputation concerns

Myanmar's long-standing internal conflict continues. The new government has made signing a peace agreement with ethnic armed military groups a top priority. The Thein Sein government proposed a Nationwide Ceasefire Agreement with ethnic armed groups, although only some agreed to sign (Mark, 2018). The NLD government launched the 21st Century Panglong Union Peace Conference to promote broader peace talks. The first session was held in late August to early September 2016, with succeeding sessions to be held every six months. The third session has been delayed several times (Nyein, 2018; Pwint, 2018; Thar, 2018; Z. M. Win and Thiri, 2018). Negotiations have yet to be concluded.

The management of clashes in Rakhine state between the Tatmadaw (national armed forces of Myanmar) and minority Rohingya have severely affected international support for the NLD government, especially from major Western countries (Barany, 2018). Being involved in Myanmar while it is undergoing its weak democratic transition can damage an investor's reputation (Simpson, Park, Simpson, and Park, 2013).

Increasing international scepticism in the government's ability to deal with the conflict has added to such reputational risk. It is unlikely that the United States, European Union, or United Nations will re-impose international sanctions; however, reputational issues may affect companies investing in the country (Lee and Zaharia, 2017; Peel, 2017). This can be particularly troublesome for companies from predominantly Muslim countries (Rajan, 2017).

Absence from national plans

The National Electricity Master Plan (NEMP) draws on the current government's capacity expansion plan. It was drafted before the commencement of the NLD government but is now undergoing revision.

The NEMP remains the most important guiding policy in the energy sector and in fact, represents a major milestone in Myanmar's energy policy development. However, the scenario analysis underlying NEMP imposed an exogenous cap of 10% on renewables. As a result, the role of renewables in general, and solar energy in particular, is underplayed (Del Barrio–Alvarez and Sugiyama, 2018).

4.6 Discussion and Conclusions

It is widely acknowledged that renewables can play a major role in the power mix for Myanmar. This role will be fundamental for rural electrification, but need not be limited to that. Renewables, particularly solar energy, can contribute to increasing the supply and reliability of Myanmar's national grid.

Recent studies have contributed to understanding the power situation in Myanmar. However, beyond technical considerations, the government should develop an appropriate policy framework to attract international financing and expertise and to secure its needs. Since the start of the democratic transition, Myanmar's energy sector has captured the interest of development partners and international investors. However, this investment has yet to materialise in the solar energy sector in a robust, transparent manner.

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 Myanmar³

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.

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 Mitsu 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):

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

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.

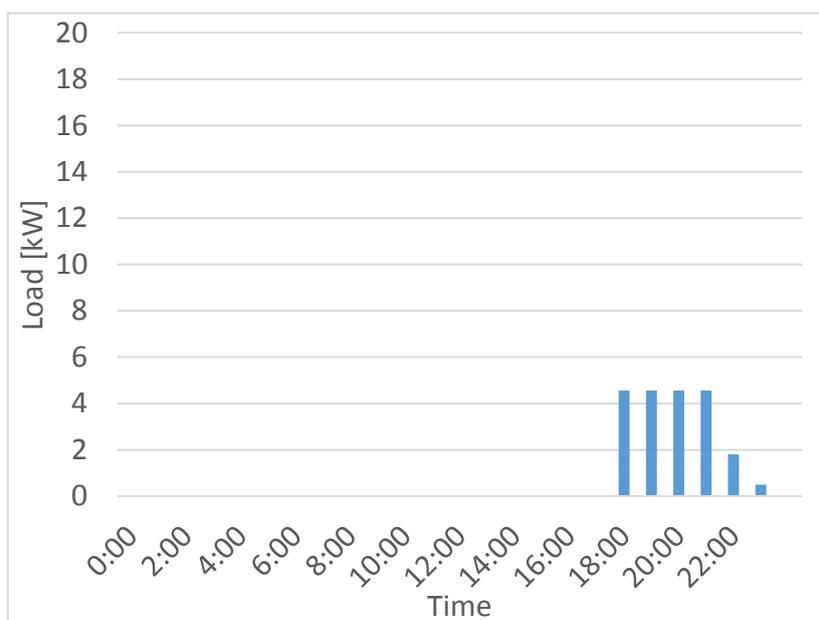
5.2.3 Load Assumption

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.

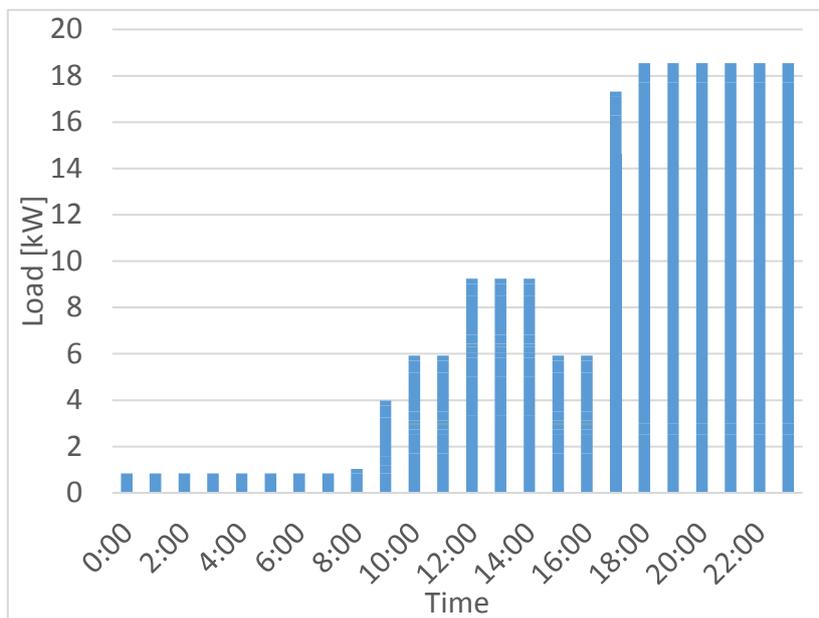
Scenario B is a higher load case representing both household use at night and productive use during the daytime. ‘Household use’ was assumed to refer to appliances that households wish to have in the future, based on a feasibility study done by one of the developers. ‘Productive use’ was assumed to refer 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.

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 2.7⁵ (FP × 2.7) for rural areas. The international fuel price is based on forecasts by the US EIA (2015).⁵

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

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 5-4 We 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 ^x /kWh (Kittner et al., 2017)
Operation & Maintenance cost	US\$0 /kW (Lazard, 2017)	US\$0.04/kWh (Lazard, 2017)
Replacement ^{x,x}	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)

^xIn 2015 US\$.

^{x,x}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).

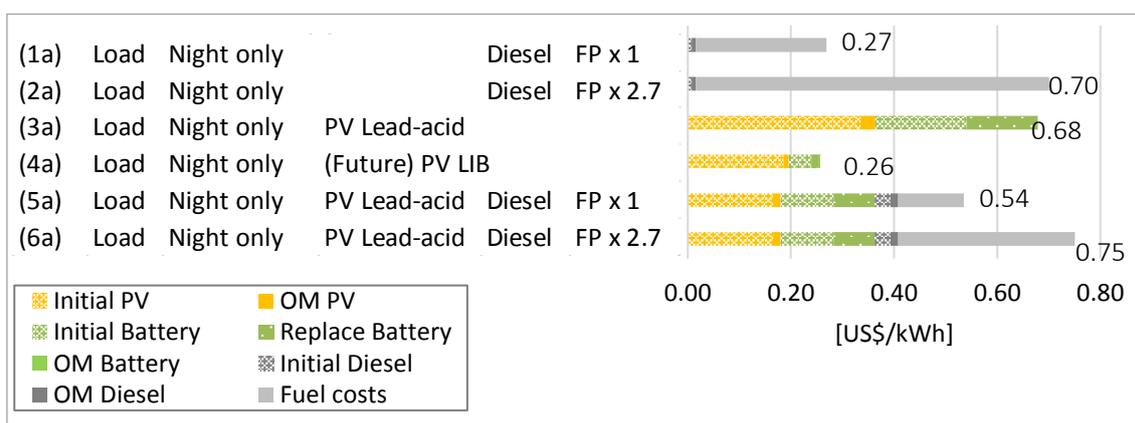
It is not necessarily appropriate to suggest that the LCOE becomes less expensive after combining solar PVs, batteries, and a diesel generator. Each component's capacity was set following the configuration of Blum et al. (2013), but the optimal combination should be further investigated. The system capacities 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.

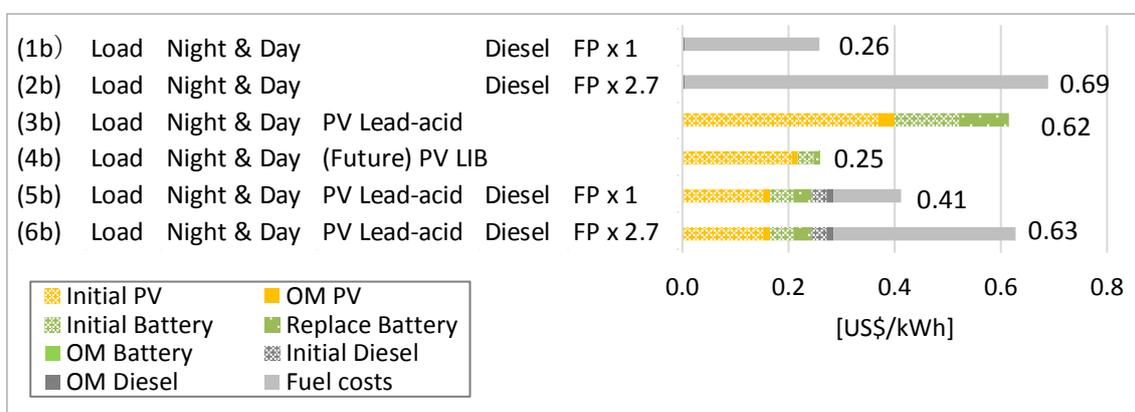
Figure 5-3. Calculation Results of LCOE: Load A (Night Only)



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\$0.036⁶/kWh (ADB, 2016) and was heavily subsidised. It is nearly 10 times higher than the mini-grid's tariff.

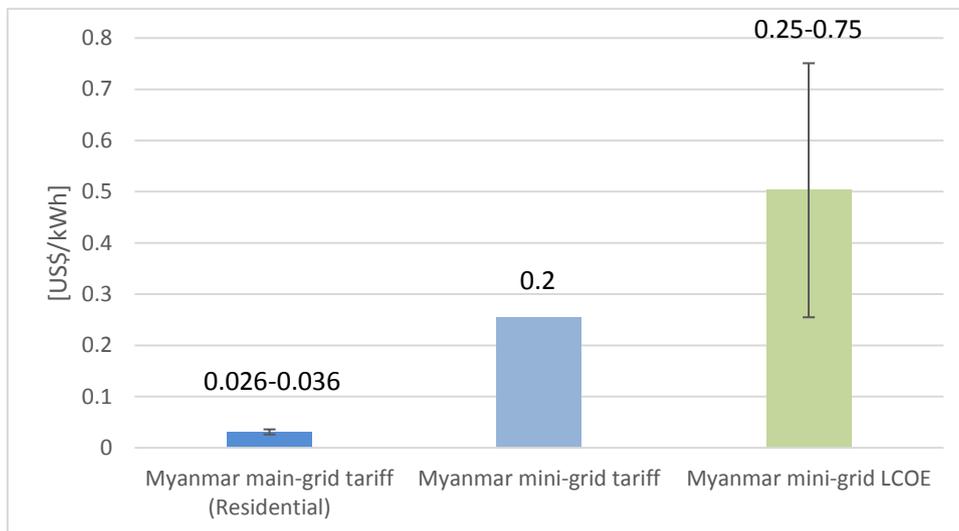
5.3 Barriers to Development of Mini-grids

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

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 them 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, Siyambalapatiya, 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 Myanmar⁷, 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 minigrad 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

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 developed, 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.

Chapter 6

Environmental and Social Guidelines on China's Foreign Investments and the Myitsone Dam Controversy

In 2011, a mega project in Myanmar called the Myitsone hydropower development was suspended. This chapter attempts to explain the link between the suspension and China's 'Guidelines for Environmental Protection in Foreign Investment and Cooperation', through the lens of the first two stages of Anthony Downs' Issue Attention Cycle – in particular, the 'alarmed discovery and euphoric enthusiasm' phase.

This chapter underscores the need for international communities to help create communication lines between foreign investors and local communities as early as the pre-project phase of any large-scale hydropower development project.

6.1 Introduction

On 28 February 2013, China's Ministry of Commerce and Ministry of Environmental Protection released its 'Guidelines for Environmental Protection in Foreign Investment and Cooperation', a document that defines how Chinese investors should safeguard the host countries' local environmental and social interests. Many nations have long been calling for such a move, recognising the serious adverse impact of China's foreign direct investment and fearing that any existing damage will likely worsen in the near future.

The guideline is composed of 22 articles that refer to compliance with local laws and regulations of the host country; the need to safeguard local culture and society; the importance of creating environmental and disaster management plans as well as mitigating adverse impacts; caring for the local community; disposal of industrial wastewater; international environmental standards, etc.⁸ According to International Rivers, the United States-based international nongovernmental organisation, the guideline contains two important aspects: 'dialogue with the local community' and 'mitigation of environmental impacts' (International Rivers 2013b).⁹

Dialogues with the local community are covered in five articles:

- 1) The enterprise must respect the local religion, culture, and custom to facilitate harmonious development with the local economy, environment, and society (Article 3);
- 2) In line with local laws and regulations, the enterprise must establish and maintain a

⁸ For the full guideline in English, see the Appendix. For the original Chinese version, see <http://www.mofcom.gov.cn/article/b/bf/201302/20130200039930.shtml>.

communication channel with local communities as part of the project's environmental and social responsibility, and must also consider the opinions and suggestions (pertaining to projects) of the community's residents through public hearings and consultations (Article 20);

- 3) The enterprise must prepare and publish a project plan that complies the local laws and regulations, and disclose information regarding the environment affected by the project (Article 18);
- 4) The enterprise must develop and utilise a secured communication channel with stakeholders to deal with urgent incidents and accidents (Article 14);
- 5) The enterprise must implement a sustainable development strategy to balance corporate benefits and environmental conservation (Article 4).

These next four articles relate to the mitigation of environmental impact caused by the project:

- 1) The enterprise must identify the manner of storage, transfer, reduction, recycling, and disposal of hazardous waste in the project management plan, and ensure that the level of pollution generated by the project complies with the local environmental standards through a pollution prevention plan (Articles 10, 13, and 16);
- 2) In line with local laws and industrial practices, the enterprise must prepare and implement mitigation and restoration plans in case the project's activities/systems create adverse impacts on local ecosystems (Article 15).
- 3) The enterprise must monitor and evaluate the project's impact before implementation, collect and record relevant local information, and monitor and record disposal of waste (Article 11).
- 4) The enterprise must prepare and implement a mitigation plan with regard to project-related impacts on historical and cultural monuments and tourist attractions (Article 9).

The guideline, however, could be criticised because (i) it does not mention the rights of local communities and individuals; (ii) it does not prohibit locating a project within a protected/conserved area (such as those containing world heritage structures, or environmentally valuable areas such as national parks); and (iii) it cannot possibly lead to project cancellation even if impact mitigation is impossible, although it emphasises this point as a requirement. While these criticisms are reasonable, the publication of this guideline could be seen as a positive first step towards ensuring that China enterprises with foreign direct investments are taking measures to safeguard project-affected local communities and their environment.

The section below provides the analytical framework used in the discussion of the guideline vis-à-vis the Issue Attention Cycle. The third section presents a case study, – the suspension of the Myitsone Dam project in Myanmar – and analyses it in relation to this framework. The fourth section expands on this analysis by tackling the endogenous and exogenous factors that affected this case. The fifth and last section provides recommendations.

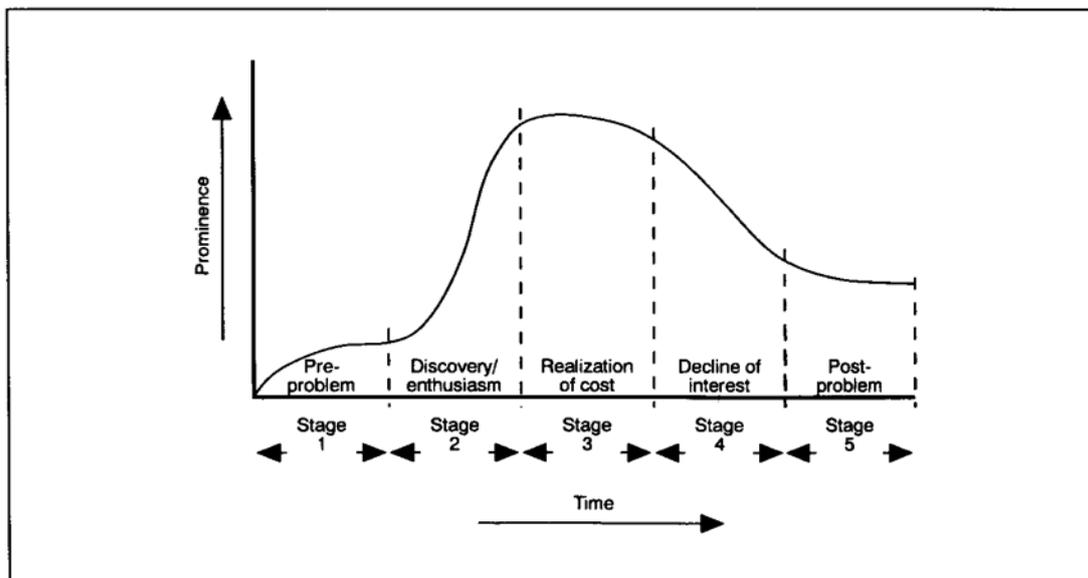
6.2 Analytical Methodology

6.2.1 Issue Attention Cycle Framework

The relationship between issue-attention and decision-making can be defined via a popular concept known as Downs' Issue Attention Cycle. In this concept, Downs argued that public concerns on environmental problems is often cyclical, which forces critical decision-making at a certain point. He noted that a problem 'leaps into prominence, remains there for a short time, and then, though still largely unresolved, gradually fades from the centre of public attention' (Downs, 1972). In its original form, the environmental problems in the 1960s were analysed. Also, It has since been found to be applicable in understanding the relationship between policy decisions and public interests in certain issues (Cohen, 1963; Iyengar and Kinder, 1987; Walker, 1977).

According to Downs, each stage is summarised as follows (Figure 6-1):

Figure 6-1. Public Interest in the Issue Attention Cycle



Source: Staggenborg, 2015.

Stage 1. The pre-problem: In this stage, undesirable social conditions have not yet caught the public's attention. Meanwhile, experts and interest groups have already cautioned about the undue impact.

Stage 2. Alarmed discovery and euphoric enthusiasm: A series of events (or other reasons) catches the public's awareness. The public is now alarmed about the negative side of an issue. This alarmed discovery is invariably followed by euphoric enthusiasm over society's ability to solve the problem effectively in a short time.

Stage 3. **Realising the cost of significant progress:** In the third stage, the public gradually realises the high cost of ‘solving the problem’. Eventually, not only a considerable amount of money but also significant sacrifices from a certain interest group are required to solve the problem.

Stage 4. **Gradual decline of intense public interest:** The realisation of the cost in the previous stage leads to a gradual decline in the public’s interest. As more people realise how difficult and costly it would be to resolve the issue themselves, public desire to keep attention focused on the issue consequently wanes.

Stage 5. **Post-problem stage:** In the final stage, the issue that was at the centre of public concern is now replaced by some other concern. The initial issue then moves into a prolonged limbo; it receives lesser attention than it did in the beginning (Stage 1) or experiences short-lived recurrences of interest.

6.2.2 Application of the Framework

While the framework mentions the cyclical character of public attention on a certain issue, it also assumes that important decisions are reached when there is an increasing public interest in the issue, particularly in Stage 2. Following this assumption, the publication of the guideline in 2013 may be perceived as related to Stage 2 in the cycle.

At first blush, many might assume that the release of the guideline has been driven by relevant public interests in China itself. Yet, this study does not take this view for the following reasons: First, the Chinese government is less accountable towards its own people compared to a democratic government. Second, it is unlikely that the Chinese public’s interest in the environmental and social safeguards in foreign direct investment has risen significantly. Instead, this chapter sheds light on the public interest around projects *outside* China, and addresses its connection to the publication of the guideline in China.

This look at the connection is via a comparative study of Chinese-led dam projects in Myanmar, Lao PDR, and Cambodia (Kirchherr et al., 2017). While this study mentions the Myitsone dam controversy as a game changer, it does not delve into the details of the case. Rather, the study analyses public interest in the controversy through in-depth personal interviews and analysis of primary data. First, the study focuses on the role of the Global Environmental Institute (GEI), the party that drafted the guideline.

Then, it narrows down the focus of the interviews on the recent halt of the Myitsone hydropower project in Myanmar. The next section thus describes how this process moves from Stage 1 to Stage 2 of the Downs’ framework.

6.3 Cancellation of the Myitsone Dam project: from Stage 1 to Stage 2

6.3.1 Pre-problem Stage

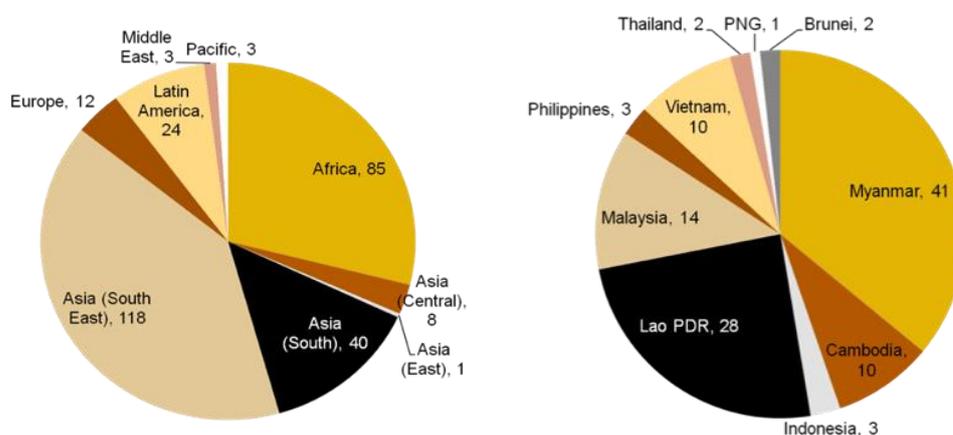
China has invested heavily in hydropower dams all over the world (Figure 6-2)). In terms of the number of projects, Southeast Asia is China's biggest market, followed by Africa and South Asia. In Southeast Asia, some of China's biggest markets are Myanmar, Lao PDR, and Cambodia, together with Viet Nam and Malaysia.

Myanmar, Lao PDR, and Cambodia recently attracted considerable foreign direct investment from China (Figure 6-3). While Cambodia recorded an increase in Chinese-invested dams since 2010, the number in Lao PDR has surged since 2011. On the other hand, Myanmar, which was gradually democratised under the former President U Thein Sein, has been seeing serious public outcry over hydropower projects since 2011.

The International community has long criticised China's investments in dams outside of its country for its lack of environmental and social safeguards.¹⁰ While this problem was not recognised by the Chinese public, nongovernmental organisations have been slowly highlighting its observations since the mid-2000s. In 2008, GEI eventually drafted the guideline in collaboration with the Ministry of Environmental Protection.¹¹

The Ministry of Commerce's hesitance delayed the government's approval on the publication of the guideline. Although environmental issues had already been raised during that period, the Ministry of Commerce did not relent. As the draft was not opened to the public, it never stirred any public discussion.

Figure 6-2. Number of Chinese Hydropower Development



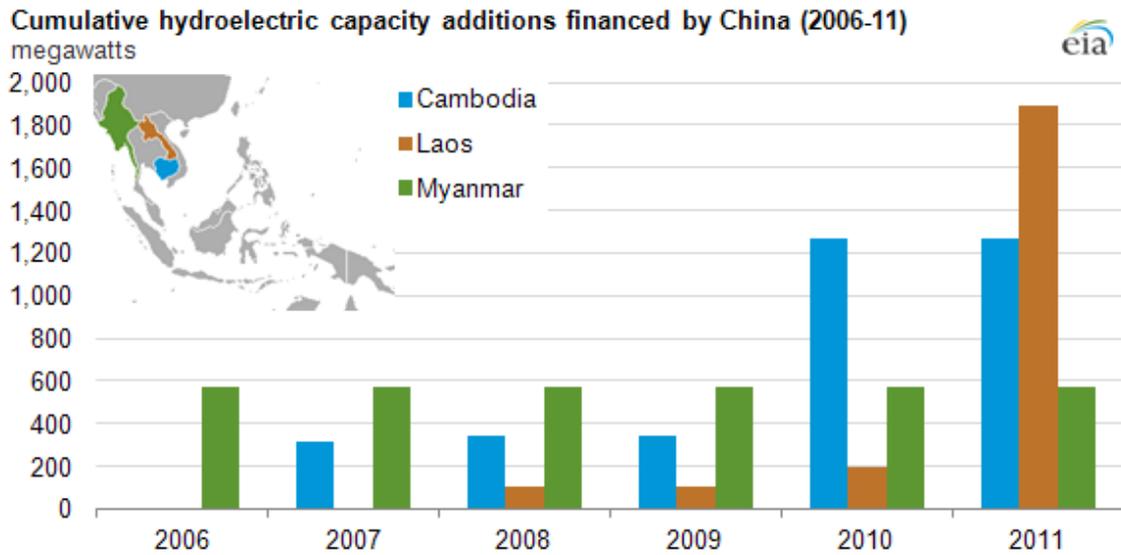
Source: International Rivers (2012).

¹⁰ For example, see 'China: New Dam Builder for the World', *Wall Street Journal* (28 December 2007) and 'Bui Dam Workers Up Against Chinese Employers', *Modern Ghana* (26 May 2008).

<https://www.modernghana.com/news/167059/1/bui-dam-workers-up-against-chinese-employers.html>

¹¹ Ji Lin, Global Environmental Institute, Interviewed by the author, 3 February 2018.

Figure 6-3. Chinese Hydropower Development in Cambodia, Lao PDR, and Myanmar



Source: Association of Southeast Asian Nations (2013).

6.3.2 Myitsone Development: Deepening Ties Between China and Myanmar

The temporary suspension of the Myitsone Dam took place in 2011, two years before the guideline’s release in 2013.

The Myitsone Dam is located in Kachin State in northern Myanmar, and is home to one of the country’s minorities, the Kachin people (Figure 6-4). The project consortium consisted of the China Power Investment Corporation (CPI), Ministry of Power No. 1 of Myanmar, and Myanmar’s Asia World Company. Its total investment was US\$3.6 billion. Had the project been completed in 2017 as planned – with its total capacity of 6000 MW – the Myitsone hydropower project would have been one of the largest in Myanmar and even Southeast Asia. Yet, former President U Thein Sein suddenly announced a halt to the dam’s development during his tenure in 2011. The decision was made because although Myanmar had improved its ties with China, it was confronted with severe sanctions from Western countries in the 2000s.¹²

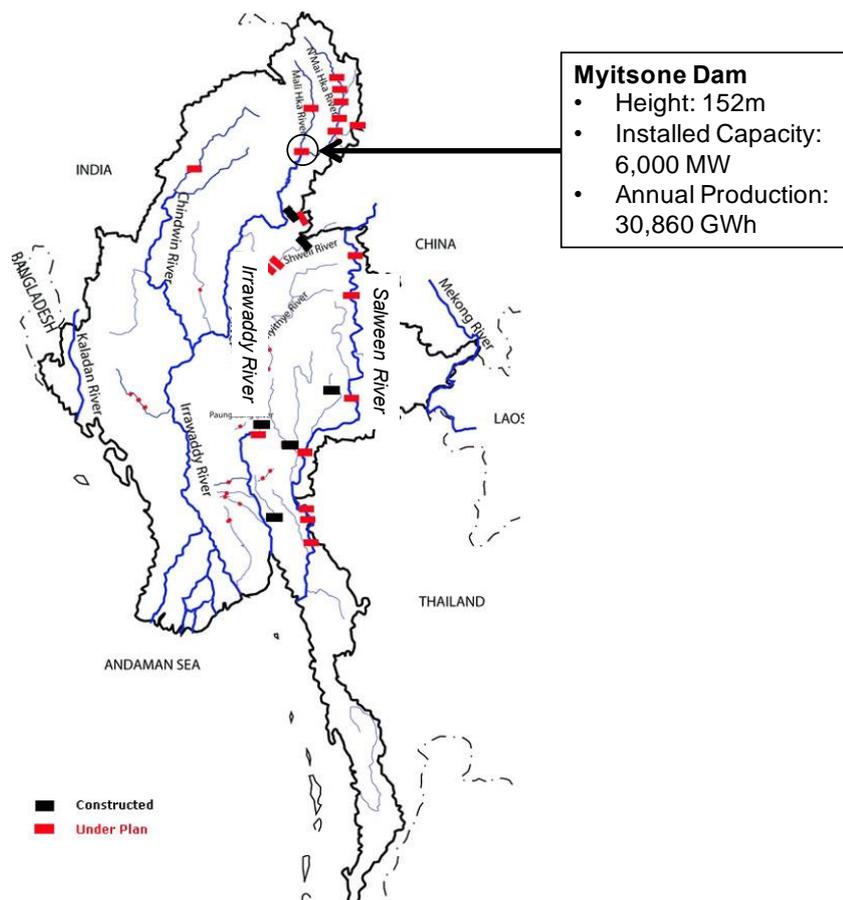
Some key events that occurred prior to President U Thein Sein’s decision are chronicled below. In June 2000, General Maung Aye, vice-chairman of the State Peace and Development Council, announced China and Myanmar’s joint statement on a cooperative framework. In July 2000, Vice-President Hu Jintao visited Myanmar and discussed a cooperative agreement on science and technology between the two countries. One year later, China and Myanmar signed a cooperative agreement on geology and mining. In December 2001, President Jiang Zemin visited Myanmar and signed the agreement on the promotion of trade and investment. In March 2004,

¹² Regarding this deepening relationship, see Shee (2005) and Shao and Fan (2005), for example.

Wu Yi, vice-premier of the State Council, visited Myanmar and signed the MoU on the promotion of investment and trade according to the Economic and Commercial Counsellor's Office of the Embassy of the People's Republic of China in the Republic of the Union of Myanmar.

After Prime Minister Khin Nyunt was replaced by Soe Win in October 2004 (an event brought about by pressure from the Bush/US administration), the cooperation between China and Myanmar even grew stronger. In April 2005, Chinese President Hu Jintao met with Myanmar's President Than Shwe in Jakarta to agree to new bilateral relationships (People's Daily Online, 2005). In February 2006, Chinese Premier Wen Jiabao met with the group led by Myanmar Prime Minister Soe Win and agreed on the early initiation of some prioritised projects. Under this agreement, Myanmar expressed its expectation for heightened cooperation and higher investment from Chinese corporations in the energy sector (Sohu News, 2006). In December of the same year, high-ranking officers from the Ministry of Power No. 1 of Myanmar visited Kunming to request additional energy investments from Chinese corporations.

Figure 6-4. Location of the Myitsone Hydropower Development Project



Source: Burma Rivers Network.

Accordingly, in December 2006, the CPI eventually agreed on an MoU with the Ministry of Power No. 1 of Myanmar for new development projects in the Irrawaddy Basin. These projects included the 6,000 MW dam at Myitsone and the 3,400 MW dam at Chibwe.

In 2007, the Changjiang Design Institute of China sent designers to dam sites to conduct geological drilling, reservoir inspection, and hydrological measurements. In 2009, Myanmar Ambassador Thein Lwin and CPI President Lu Qizhou signed a build-operate-transfer MoU for hydropower projects such as the one in Myitsone (Burma Rivers Network, 2009). In December 2009, CPI started planning of the hydropower project in the upper Irrawaddy (Ayeyarwady) Basin. In June 2010, the Ministry of Power No. 1 of Myanmar and CPI signed the construction agreement in the presence of both Chinese Premier Wen Jiabao and Myanmar President U Thein Sein (Xinhua Net, 2010).

6.3.3 Cancellation of Myitsone Project: Alarming Discovery and Euphoric Enthusiasm (Stage 2)

After early 2011, the relationship between Myanmar and China reversed completely. Two political events were responsible for this shift. First, the Obama Administration reversed the Bush Administration's diplomatic policy on Myanmar for three reasons (Liu, 2010): (i) The US diplomacy changed its focus from hard power to soft power after the economic crisis in 2009; (ii) The United States began to view ASEAN countries as a platform for its Asian diplomacy; and (iii) China has always exerted a strong influence in the ASEAN region. As a consequence, the Obama administration took a friendlier stance towards ASEAN countries, including Myanmar (Xie and Liang, 2011).

Second, from the viewpoint of the Thein Sein administration, the changing diplomatic attitude of the United States was favourable as it could give Myanmar the opportunity to request that the sanctions imposed on the country be lifted. This was necessary to achieve tangible economic development after democratisation under Thein Sein's leadership. In this regard, Thein Sein eventually released one of the world's most important political figures, Aung San Suu Kyi in March 2011. Swiftly, in August of that year, Suu Kyi started 'Save the Irrawaddy' campaign with an open letter to the public, mentioning four points (Burma Partnership, 2011). (i) Irrawaddy (Ayeyarwady) is the most important river in the country; (ii) Dam development is problematic since it threatens the river; (iii) Problems resulting from the Myitsone dam development include security, livelihood, nationality, and diplomatic aspects; and (iv) People are called upon to participate in 'Save the Irrawaddy' campaign. In this way, the NLD – the party led by Aung San Suu Kyi – strategically positioned the controversial Myitsone project as an issue for the 2012 elections. The Thein Sein administration could not ignore this growing campaign, which was also backed by the international community, and eventually announced a halt to the project in September 2011.

While the campaign never specifically blamed China for the project, it created considerable anti-Chinese sentiment in Myanmar. For example, local groups listed the following as reasons to stop

the Myitsone hydropower project.¹³ (i) Construction of the dam caused social issues because of the forced relocations of more than 60 villages and 10,000 residents; (ii) The electricity produced would be primarily exported to China, with the remaining being distributed between Myanmar's military and corporations. Therefore, the project will not benefit local communities; (iii) Energy export from Myitsone would provide an annual benefit of US\$500 million to the military government but a higher US\$3.6 billion to China; (iv) No relevant social and environmental impact assessments have been prepared; (v) Stakeholder meetings with concerned local communities have not been held; (vi) The project has no monitoring system in-charge; (vii) The dam site holds enormous cultural significance to the Kachin people; (viii) The dam will change the river's flow, damaging fisheries downstream; (ix) As the location is a conflict-prone zone, the dam is likely to suffer damage from potential conflicts; (x) Dam construction will lead to forced labour and human rights violations by the Burmese military; (xi) The dam is located in an earthquake-prone area; (xii) Drainage containing methyl alcohol could pollute the waters used by communities living downstream; and (xiii) the Chinese company absolves itself of full responsibility in sustaining the livelihood of the affected local community. Thus, China was an implicitly accused party in the Myitsone project.¹⁴

This growing anti-Chinese sentiment posed a serious barrier to China's expansion policy in the ASEAN region. Thus, it had to prove its willingness to be flexible with the locals' demands. One of China's responses in 2013 was to publish the guideline, the document that had previously been stalled by its Ministry of Commerce.¹⁵

6.4 Other Endogenous and Exogenous Factors

Aside from the factors listed above, there could be other considerations that led to the tipping point. One set of considerations is the endogenous factors in the Chinese policy. The year 2013 was not just the year the guideline was published. It also marked the year of transition from the China's 11th Five-Year Plan (2006–2010) to the 12th Five-Year Plan (2011–2015). This policy change could have affected the attitude of the Ministry of Commerce to favour the guideline's release.

Critics also noted that external pressures other than those pertaining to the Myitsone hydropower project could have brought about this change. There were other projects considered controversial at the time, which could also have influenced the Chinese government's stance.

¹³ See Burma Rivers Network website < <http://www.burmariversnetwork.org> >.

¹⁴ Arguably, the United States might have played a role in this process. See 'US Embassy Cables: How Rangoon Office Helped Opponents of Myitsone Dam', *The Guardian* (30 September 2011) < <http://www.theguardian.com/world/2011/sep/30/us-embassy-cables-myitsone-dam-document> > and 'WikiLeaks cables: Americans funded groups that stalled Burma dam project', *The Guardian* (30 September 2011) < <http://www.theguardian.com/world/2011/sep/30/us-embassy-cables-burma-myitsone-dam> >.

¹⁵ Ji Lin, Global Environmental Institute, interviewed by the author, 3 February 2018.

6.4.1 Environmental Concerns in the 12th Five-Year Plan

The 12th Five-Year Plan (2011–2015) consists of 16 comprehensive chapters. It imposes more stringent environmental targets compared to the previous plan. First, the energy consumption rate was targeted to reach 16%, which is more ambitious than the previous target of 20%. Second, the target for non-fossil fuel use was set at 11.4%, (compared with 7.5% in 2011). Third, CO₂ emission intensities were to be reduced by 17% compared to the 2010 level. Fourth, the annual reduction rates of SO₂ and NO_x were targeted at 8% and 10%, respectively, compared to 2010 levels. Moreover, China has arguably been trying to move beyond coal (Horii, 2011).

However, this environmentally friendly stance only applies to the country's domestic investment policy and not to its external investment plan. For domestic investments, energy-efficient and environmentally friendly technologies enjoy the Chinese government's support in the form of assistance with Research and Development and an advanced industry. In contrast, environmental and social safeguards were never considered for external investments. Instead, to highlight internal and external investments together as one of the four pillars in its Five-Year Plan, the Chinese government has made a strong push for external investment without paying heed to environmental and social safeguards.

6.4.2 Environmental Controversies in 2008–2013

The period 2008–2013 was marked by environmental controversies in countries other than Myanmar. For instance, consider the Kamchay Dam in Cambodia, which has a design capacity of 200 MW. A build-operate-transfer contract was agreed upon between Sinohydro and the Ministry of Mines and Resources of Cambodia in 2008. Although nongovernmental organisations highlighted environmental and social concerns associated with the dam and complained about insufficient information disclosure, the developer proceeded with the construction so that the dam could commence operation in December 2011.

Another case is that of the Lower Sesan 2 Dam in Cambodia, which has a total capacity of 400 MW. In 2012, Hydrolancang International signed the contract to construct the dam. The dam was started in February 2014 but became controversial because it did not satisfy the international environmental impact assessment standards. However, the company was able to complete the structure in September 2017.

While both cases were marred by environmental and social problems and stirred local controversies, they never attracted enough public attention to compel developers to suspend the projects.

In 2014, International Rivers reported that Myanmar has the distinction of being the country with the highest number of suspended dam projects (International Rivers, 2013a). Besides the Myitsone Dam, Myanmar had suspended five other dam projects; namely, Chibwe (2,800 MW), Khaunlanphu (2,700 MW), and Lakin (1,400 MW) Dams in the N'Mai River Basin; and the Dagwin (800 MW) and Weigyi (4,540 MW) Dams in the Salween Watershed. These projects were funded and originally set to be constructed by Chinese companies. Yet, as seen in the previous section,

the 'Save the Irrawaddy' campaign was led by the NLD party before the 2012 election, but only the Myitsone controversy led to the rise of anti-Chinese sentiments. Eventually, the Chinese government could not ignore this turn of events.

6.5 Conclusion: Summary and Implications

This chapter attempted to explain the link between the release of the 'Guidelines for Environmental Protection in Foreign Investment and Cooperation' and the first two stages of Downs' Issue Attention Cycle surrounding the stalled Myitsone hydropower project in Myanmar. As Downs noted, the guideline was published in 2013, immediately after the attention on the Myitsone hydropower as well as anti-Chinese sentiment in Myanmar peaked. Thus, the Issue Attention Cycle model – which was originally applicable to democratic institutions – might also be applicable to the decision-making process in China, a country characterised by a socialist market economy.¹⁶

The environmental nongovernmental organisation GEI has played an indirect role in connecting the issue and the public interest in Myanmar and the eventual decision of the Chinese government.

It can be argued that regardless of GEI's actions, the Chinese government would have had responded to the growing anti-Chinese sentiment in Myanmar due to the Myitsone controversy. Nevertheless, one needs to acknowledge that without GEI's preparation of the draft in 2008, the guideline might not have been published in its current form in 2013. Global Environmental Institute, therefore, helped expedite the Chinese government's response to the Myitsone issue.

Thus, the following are policy implications regarding China's environmental safeguard policies on its external investments: First, as early as the 'pre-problem' stage, specific policy design and recommendations must include ways to tackle latent problems at the outset. At this stage, such policy advocacy may not have an effective outcome, considering the low accountability of Chinese policy-making. Yet, as shown by the experience pertaining to GEI's draft, such advocacy will see results in the long run. To address environmental and social issues, collaboration with the Ministry of Environmental Protection can be a strategy worth taking.

Second, in the 'alarmed discovery and euphoric enthusiasm' stage, the Chinese government must ensure that the policy-based strategy developed during the 'pre-problem' stage effectively responds to the public's concerns. So far, the Chinese government and companies have not effectively dealt with the anti-Chinese sentiment. It is often said that they lack competence in public diplomacy, which unfortunately lowers their image (Kittner and Yamaguchi, 2017; Yamaguchi et al., 2018). In this context, the Chinese government also needs an effective policy to deal with anti-Chinese sentiments in the countries it invests in.

¹⁶ Kingdon's 'Agenda Setting Model' could be similarly applied to the Chinese policy-making process. For example, see Liu and Yamaguchi (2017).

Finally, to take this study one step further, it is crucial to monitor the effective implementation of a policy during the later stages – that is, when the public’s attention starts to fade. As shown in other cases, the policy implementation process can be problematic if it does not have the public’s attention.¹⁷ It is quite difficult, however, to ensure the effective implementation of the Chinese policy on external investments, as China does not have any accountability over policies implemented outside its borders. Thus, future research should look at how effective policies are being implemented with regard the ‘Guidelines for Environmental Protection in Foreign Investment and Cooperation.’

¹⁷ For example, see Hall (2002).

Chapter 7

Policy Recommendations

This whole report approached the power sector policy of Myanmar from a range of perspectives, covering integrated energy/environmental assessment of large-scale hydropower, techno-economic assessment of mini-grids, qualitative policy analysis of utility-scale solar and mini-grids, and China's approach towards hydropower projects. Lessons have been distilled from each chapter and integrated in the following policy recommendations.

7.1 The Main Grid and Expansion of Its Power Capacity

Alternative power development plans that do acknowledge the possible negative consequence of large-scale hydropower plants can contribute to ecological and social stability while achieving economic efficiency. Concentrating one's option on large-scale hydropower could potentially threaten the ecosystem and social stability. Fortunately, the rapidly falling cost of emerging renewable energy technologies – including solar, biomass, and battery storage – is one reason alternatives' capacity expansion pathways must be reconsidered. At the same time, there must be a more concerted effort to accurately estimate (i) the technical resource potential of solar and other non-hydropower-based renewables in a community; and (ii) the developers' ability to fund new projects if one were to improve the electricity system's reliability and reach in an area.

Coal-fired power plants and large-scale hydropower can create a new set of stranded assets under future power development scenarios. Including solar energy into the mix can diversify the power source portfolio, distribute the risk across a large number of projects and make the transition towards clean energy faster and more cost effective. Stranded assets are one of the significant financial risks in large-scale energy infrastructure projects, which include hydropower. The lack of constant or predictable future revenues from new energy system investments could put a project at risk of bankruptcy. Solar and distributed energy resource options offer operators a diversified portfolio approach that can reduce the financial risk of having stranded assets.

Myanmar can take advantage of the falling cost of solar electricity by making a strategic priority in its power development plan. Participation in financial instruments such as renewable energy auctions allows low-cost utility-solar projects to directly compete with large-scale hydropower projects.

There is an important PV potential that is currently not being utilised in Myanmar. That is, by developing the utility-scale solar generation in the Central Dry Zone, Myanmar can improve its power generation mix in a relatively short period. Connection to the national grid can be done without having to invest in long-distance new transmission lines (although re-enforcements of the infrastructure would most likely be required).

7.2 Rural Electrification with Renewable-based Mini-grids

To accelerate the diffusion of mini-grids and make mini-grid businesses sustainable, the business sector's use of electricity during daytime in rural areas should be encouraged.

Productive use of electricity during daytime in rural areas should be encouraged to make the mini-grid business sustainable.

Another way to make business sustainable is to improve the entrepreneurship knowhow of mini-grid developers/operators, most of whom have engineering backgrounds and are not entrepreneurs. A support programme for villagers on how to start new businesses will be useful.

Mini-grid developers/operators are in need of a supportive financing scheme. Appropriate financial support should be provided to mini-grid developers/operators, who often face difficulties with regard project financing. Myanmar's financial sector needs to be further developed to keep pace with foreign investments in the country. International investment, including the development of mini-grids, should also be matched with local needs.

To sustain quality, there is an urgent need to define the technical standards for renewable energy equipment. Regulatory frameworks for off-grid systems and technical standards or codes for solar PV modules do not yet exist as of this writing, which means some energy sector players suffer from using poor quality equipment. This tarnishes the image of renewable energy systems.

To make electrification efficient, a single governmental body should be responsible for dealing with both on-grid and off-grid measures. While the MOEE is currently working to extend the main grids, the DRD of the Ministry of Agriculture Livestock and Irrigation pursues both solar home systems and mini-grids as off-grid measures. At the moment, coordinating mechanisms are lacking between the two ministries. Institutional reforms are needed in this case.

7.3 Investment Environments and Connectivity

Developing a policy framework that will streamline investments should be a priority of the government of Myanmar. Currently, energy projects in Myanmar are negotiated bilaterally, which has limitations in attracting investments for a large number of projects. Promoting a healthy competition amongst investors would enable the most suitable projects to be selected in both financial and nonfinancial terms. A transparent and secure investment climate is needed.

Participation in a regional power grid market (e.g., Greater Mekong Subregion, ASEAN Power Grid, and the South Asia Subregional Economic Cooperation) will give Myanmar opportunities to expand its access to electricity, meet rising urban power demand and minimise environmental and societal risks. Further regional integration could smoothen tensions with investors from neighbouring countries as well as create reliable electricity export revenues without causing ecological or social issues. Importing electricity from neighbouring countries with excess supply can also quickly alleviate frequent blackouts, a lack of a reliable grid, and

balance loads during peak periods. At the same time, it can allow for incremental investments and quicker access to electricity for underserved populations in rural areas.

When adopting policies from other countries, both the government of Myanmar and development partners should consider the country's context. The international community already has a relatively broad experience with different policy instruments in promoting the deployment of renewables. Feed-in tariffs and renewable purchase obligations have been applied for some time. In recent years, energy auctions have been proven effective in identifying and reducing the prices of renewables in many countries. Myanmar could use that experience for its own needs. The assistance of development partners would be very valuable in this process. However, Myanmar's circumstances with regard its socioeconomic and political situation should be taken into account. For example, how to secure land in an appropriate manner should be seriously considered when implementing policies in Myanmar.

International society should help secure communication lines between foreign investors and local communities during the pre-project phase of large-scale hydropower developments. There has recently been a move to institutionalise the environmental impact assessment and strategic environmental assessment processes for hydropower projects. However, what are often lacking during the pre-project phase are open communication lines between foreign investors and local communities. Setting up this communication line at the onset may not only prevent potential environmental and social issues but also avert any economic loss brought by a public outcry or opposition.

Capacity building programmes are required to achieve all the above measures effectively. The programme should target administrative officers as well as other stakeholders such as parliament members. Often, problems in implementation are not due to technocrats' capacity but to the system employed by the relevant offices involved. In the energy sector in particular, it is critical to develop the competences and define the functions of the energy regulatory commission per the stipulations in the country's Electricity Law.

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Appendix 1: Workshop Report
The Energy Policy Workshop

Date	Wednesday, March 28, 2018
Venue	Hilton Hotel, Nay Pyi Taw
Hosted by	Central Economic Committee (CEC) National League for Democracy (NLD) Policy Alternatives Research Institute (PARI), the University of Tokyo
Supported by	The Association for Overseas Technical Cooperation and Sustainable Partnerships (AOTS) Economic Research Institute for ASEAN and East Asia (ERIA)
Language	English

Date	Morning	Afternoon
28 MAR. (WED)	<u>Ceremony (11:00–13:00)</u> Inauguration Ceremony	Lecture 1 (15:00–17:00) Overview of Energy Policy 1) Global Trend and Opportunities in Myanmar 2) Some Key Issues: - Black-out - Rural Electrification - Electricity Tariff - etc 3) Planning and Operation Prof. Hisashi Yoshikawa Project Professor Policy Alternatives Research Institute The University of Tokyo
		<i>Lunch (13:30-14:30)</i> <i>Coffee Break(15:30-15:40)</i> <i>Welcome Dinner (18:00-)</i>

29 MAR (THU)	<u>Lecture 2 (10:00–12:30)</u>	<i>Lunch (13:00-14:00)</i>	<u>Lecture 3 (14:30–16:30)</u>
	Brainstorming (Group Discussion)		Session Wrap-up (Group Presentation)
	1) Energy for Peace 2) Demarcation amongst Stakeholders - Parliament - Public Administration		1) Group Presentation 2) Response from Lectures 3) Way Forward - Action Plan

Appendix 2: Model Parameters for Energy Planning Model

Resource Potential: Refers to the total energy potential of each resource in the region

Available Portfolio: Refers to the total energy potential remaining after installed capacity

Capacity Constraints under Scenario: This section allows the model to account for future planned capacity reported in regional planning policy documents. The model can choose to constrain itself to this future planned capacity

Capacity Factor: This refers to the annual capacity factor of each generation resource

Peak Contribution: The at-peak contribution (firm capacity) for each technology. For example, for an evening peak demand profile, solar should have a 0% contribution. This constraint can be relaxed by making all resource peak contributions 100%

Load: Refers to the local electricity demand for the region, excluding exports

Load + Exports: Refers to the local electricity demand for the region, including exports

Peak Demand: Refers to the local peak electricity demand in the region

Reserve Margin: This allows the generation portfolio to meet a surplus of demand, as is the standard for operating reliable grids

Cap Cost: Refers to the overnight capital cost of each technology

Annual Cap Cost: Refers to the annualised overnight capital cost of each technology, using a discount rate and estimated lifespan

Variable Cost: Refers to the operating and maintenance cost, plus fuel cost of each technology

Investment Decision: This is the decision variable of the OpenSolver. It refers to new generation capacity installed each year. This should never be changed manually

Installed Capacity/Dispatch: This is the total installed generation capacity, assuming investment decisions are carried out

Average Dispatch: This refers to the dispatch multiplied by the capacity factors

Electricity Mix: This refers to the annual generation of the installed capacity

EneCost: Refers to the energy cost of the electricity mix, using total variable costs

CapCost: Refers to the capital cost of the electricity mix, using total capital costs

TotCost: This is the sum of the energy and capital costs of the electricity mix. This is the stream of cost that is discounted to NPV and used as the minimiser of the optimisation model

AvgCost: The average cost per electricity produced

LCOE: The levelised cost of electricity

Capacity at Peak: Refers to the contribution each resource's generation can make at peak. This value should be greater than or equal to the peak demand

Renewable Energy: Refers to the portion of annual generation that comes from renewable sources

RPS Energy: Excludes large hydropower generation

% RPS from Load: The percentage of RPS energy to the total local load of the region

Fossil Energy: Refers to the portion of annual generation that comes from fossil sources

DiffLoad: The difference between annual load and annual generation, ensuring constant power supply

DiffPeakDem: The difference between the capacity at peak and the peak demand, ensuring constant power supply

Spill: Refers to the excess annual generation in the mix

Discount Rate: The rate at which cash flows are discounted, typically 7%

Total Cost: The NPV of the stream of total cost values per year, discounted

Appendix 3 : Details of Field Survey on Mini-grids

Survey Details

Because the survey data included confidential information from companies, they were anonymised. The interview survey was conducted based on the questionnaire entitled, 'Questionnaire for Supplier/developer of Solar Home Systems (SHSs)/Solar Microgrids'. The numbers acquired were averaged and used in the levelised cost of electricity (LCOE) calculation. Table A1 shows the survey details.

Table A1. Survey details

Survey 1	
Date	February 2–3, 2017
Venue	Yangon Technological University
Method	Semi-structured interview
Interviewer	The authors
Number of interviewees (companies)	7
Survey 2	
Date	April to July 2017
Method	Questionnaire
Surveyor	Mitsui Consultants Group
Number of interviewees (companies)	2
Survey 3	
Date	19–24 October 2017
Method	Open interview
Interviewer	The authors
Number of interviewees (companies)	4

Questionnaire for Survey 1

Questionnaire for Supplier/Developer of Solar Home Systems (SHSs)/solar Mini-grids

General questions (if you do not have a name card, please fill in)

1. Name of company:
2. Address:
3. E-mail:
4. Phone/mobile:

(If this information is not on the website of your company, please fill in.)

5. Owner(s) of the company:
6. Number of staff:
7. Year company was established:

Your business field

8. What kind of products do you sell?
 - Solar lanterns
 - Solar-powered pumps
 - Solar home systems
 - Solar mini-grid/microgrid systems (capacity kW ~kW)
 - Solar modules
 - Inverters
 - Mounting systems
 - Batteries
 - Others (_____)
9. What kind of services do you provide?
 - Engineering (design, preparation of permit documents, project management)
 - Procurement
 - Construction
 - Operation of mini-grids
 - Maintenance
 - Manufacturing of (_____)
10. When did you start businesses related to solar lantern/solar home systems (SHSs)/mini-grids?
()
11. Did you have any experience in the energy business before entering the (SHS)/mini-grid business?

()

12. Does your company provide any other business products/services?

()

13. How many mini-grids have you built? Or how many SHSs have you sold?

()

14. How many mini-grid projects are you working on (pipeline)?

()

15. Do you sell second-hand components? Yes/No

If yes, from where do you procure them?

()

16. In which country are the products made?

i. Solar modules

()

ii. Inverters

()

iii. Mounting systems

()

iv. Batteries

()

v. Others in question 8

()

17. From whom do you buy the components?

i. Solar modules

- Maker
- Distributor
- Other (_____)

ii. Inverters

- Maker
- Distributor
- Other (_____)

iii. Mounting systems

- Maker
- Distributor
- Other (_____)

- iv. Batteries
- Maker
 - Distributor
 - Other (_____)

- v. Others in question 8
- Maker
 - Distributor
 - Other (_____)

18. For about how much do you sell products to your customers?

- i. Solar modules
- About () kyat <100/1,000 units (*circle the number nearest to the units your consumers typically purchase*)
- About () kyat >100/1,000 units

- ii. Inverters
- () kW: About () kyat
- If there are other inverters, which you sell?
- () kW: About () kyat

- iii. Mounting systems
- About () kyat/kW

- iv. Batteries
- () W: About () kyat/unit
- or About () kyat/W

- v. Systems as a whole
- About () kyat/kW (Including construction costs Yes/No)

- vi. Others in question 8
- ()

19. To whom do you sell the components?

- End users
- Distributors
- Developers
- Independent power producers
- Others (_____)

20. How much do you pay for electricity at the office?

- i. Do you connect to the national grid? If yes, how much is the tariff?
- () kyat/month

If you know, () kyat/kWh

- ii. Do you have a backup generator? If yes, what is its power source?
Diesel/Solar/Other ()

21. What do you think is the barrier to your business?

(Please answer freely—e.g., revenue collection risks, the potential for theft, and central grid extension.)

**For mini-grid suppliers/developers, please continue to the next page.*

For Mini-Grid Suppliers/Developers

Your track record information

1. Where is this mini-grid? (GPS coordinates or address)
()

2. What is the installed capacity?
() kW

3. What is the power source?
1. Solar 2. Hydro 3. Diesel 4. Combination of ()
5. Other (_____)

4. Who owns this mini-grid?
 Community
 Distributor
 Developer
 Independent power producer
 Other (_____)

5. How long did it take to construct?
()

6. About how much was the investment cost?
i. Equipment () kyat
ii. Construction () kyat
iii. Other () () kyat

7. Please write the contact info for the mini-grid operator, if possible.
()

8. What is the tariff for the mini-grid's electricity?
() kyat/kWh or month (Please circle the appropriate option.)

9. If any, what kind of complaints do you receive from customers?



Questionnaire for Survey 2

Project Summary			
PV capacity			kW
Battery capacity			kWh or Ah
Diesel capacity			kW
Number of households			
Cost Breakdown			
Item	Quantity	Unit Price (US\$)	Cost (US\$)
Primary Components			
PV modules			
Inverters			
PV array rack			
Batteries (if any)			
Diesel generator (if any)			
Transportation to site			
Distribution to Households			
Lamps			
Prepayment meters			
Accessories			
Internal wiring			
Distribution cables			
Streetlight			
LED street light bulb			
Lamppost			
Cables			
Installation			
Site preparation			
Primary component installation			
Household distribution installation			
Others			
Studies and surveys			
Training			
Trials (Pretesting)			
Grand TOTAL			

Detailed Load Assumptions

Table A2. Load assumptions for scenario A

Electrical Appliance	Power Consumption	Quantity per Household	Hours of Use
Lamp inside (3W × 2, 7W × 1)	13 W	1 set	18:00–23:00
Lamp outside (streetlight)	5 W	1	18:00–24:00
TV	147 W*	0.75 (3 HHs/4 HHs)	1 hour at night
Total daily electricity consumption			20.5 kWh/day

Note: HH = household.

Assumptions without notes are based on the survey conducted by the authors.

Table A3. Load Assumption for Scenario B.

Electrical Appliance	Power Consumption	Quantity per Household	Hours of Use
Lamp inside	5 W	5	18:00–23:00
Lamp outside (streetlight)	5 W	1	18:00–24:00
TV	147 W*	1	1 hour at night
Rice cooker	584 W*	0.5	0.5* at night
Refrigerator	84 W*	0.1	24
Fan	58 W*	0.6	2.86* in the daytime
Iron	1,000 W*	0.5	0.27* in the daytime
Water pump	146 W*	0.15***	0.88* in the daytime
Computer	130 W*	0.03***	4.34* in the daytime
Printer	30 W	0.01***	2** in the daytime
Grinder	120 W**	0.03 (3 carpenters per village***)	9:00–17:00
Drilling machine	350 W**	0.03	9:00–17:00
Circular saw	1500 W**	0.03	9:00–17:00

Planer	450 W**	0.03	9:00–17:00
Sewing machine	120 W**	0.01	9:00–17:00
Total daily electricity consumption			227 kWh/day (daytime: 96, nighttime: 131)

Source: * (M. P. Aye, 2015) ; ** (Blum et al., 2013) ; *** Survey by the authors.

Appendix 4: Guidelines for Environmental Protection in Foreign Investment and Cooperation

February 18, 2013

Guidelines for Environmental Protection in Foreign Investment and Cooperation¹⁸

Source: Ministry of Commerce and Ministry of Environmental Protection of China

Article 1. These *Guidelines* are hereby formulated to direct enterprises in China to improve their regularisation of environmental protection in foreign investment and cooperation activities, to ensure timely identification and prevent environmental risks, to actively perform their social responsibilities regarding environmental protection, to set up a good international image for Chinese enterprises, and to support the sustainable development efforts of the host country.

Article 2. These *Guidelines* are applicable to the environmental protection of Chinese enterprises in foreign investment and cooperation activities, which shall be implemented consciously by enterprises.

Article 3. It is advocated that in the course of active implementation of their responsibilities on environmental protection, enterprises should respect the religious beliefs, cultural traditions, and national customs of local communities in the host country; safeguard the legitimate rights and interests of labor; offer training, employment, and re-employment opportunities to residents in the surrounding areas; promote harmonious development of the local economy, environment, and community; and cooperate to ensure mutual benefits.

Article 4. Enterprises shall adhere to the concepts of environmental friendliness and resource conservation, develop low-carbon and green economies, and implement sustainable development strategies so as to realise a 'win-win' situation, benefiting both corporate interest and environmental protection.

Article 5. Enterprises shall comprehend and implement all the provisions pertaining to the environmental protection laws and regulations of the host country.

For projects investing in construction and operation, enterprises shall file applications for environmental protection permits with the local government in accordance with the laws and regulations of the host country.

¹⁸ See the original Guidelines in Chinese at <http://www.mofcom.gov.cn/article/b/bf/201302/20130200039930.shtml> and the official English translation at <http://english.mofcom.gov.cn/article/policyrelease/bbb/201303/20130300043226.shtml>

Article 6. Enterprises shall include environmental protection as well as production and operation plans in their enterprise development strategies; establish the corresponding rules and regulations for environmental protection; and manage all aspects related to the enterprise's environment, health, and production safety. In addition, enterprises shall be encouraged to utilise integrated environmental services.

Article 7. Enterprises shall establish a sound environmental protection training system to provide employees with appropriate education and training with respect to the environment, health, and production safety. Enterprises shall enable employees to understand the relevant laws and regulations of the host country regarding environmental protection and disposal of harmful substances, prevention of environmental accidents, and other environmental aspects, so as to improve employees' awareness on regulatory issues and environmental protection.

Article 8. Enterprises shall, in accordance with the requirements of the laws and regulations of the host country, conduct an environmental impact assessment on the development and construction of all projects, as well as their production and operation activities. Enterprises shall take reasonable measures to reduce possible adverse impacts based on the findings of such environmental impact assessments.

Article 9. Enterprises are encouraged to consider the impacts of their development and construction projects as well as production and operation activities on the social environment such as historical and cultural heritage, scenic spots, and folk customs. Enterprises shall take reasonable measures to reduce possible adverse impacts.

Article 10. Enterprises shall, attending to the requirements of the laws, regulations, and standards of the host country concerning environmental protection, install and operate pollution prevention equipment, implement pollution prevention interventions, and ensure that pollutant emissions, wastewater effluent, solid waste, and all other pollutants meet the pollutant emission/discharge standards of the host country.

Article 11. Enterprises are encouraged to, prior to the construction of the project, conduct environmental monitoring and evaluation for the proposed construction site, obtain an understanding of the environmental background of the project location and its surrounding areas, and publicly disclose the environmental monitoring and evaluation results.

Enterprises are encouraged to monitor the pollutants of primary concern, be cognisant of the pollution generated by the enterprises at all times, and disclose the monitoring results.

Article 12. Enterprises are advocated to conduct environmental due diligence activities for target overseas enterprises before acquiring them, focusing the evaluation on the hazardous waste formed as part of their previous/historical operation as well as soil and underground water pollution, and environmental legacies of the target enterprises. Enterprises are encouraged to undertake best environmental practices to reduce the potential environmental risks and liabilities.

Article 13. Enterprises shall establish management plans for hazardous waste that may be generated during production, the contents of which shall include measures to reduce the

amounts and risks of hazardous waste, as well as measures to store, transport, utilise, and dispose of them.

Article 14. Regarding potential risks of environmental accidents, enterprises shall formulate contingency plans for environmental accidents and other emergencies based on the nature, features, and possible environmental hazards of the same, and set up a reporting and communication system with the local government, regulatory environmental protection authority, the general public that may be affected by the project, and the headquarters of Chinese enterprises.

Contingency plans shall include the organisational system and responsibilities pertaining to emergency management, prevention, and early warning mechanism; handling procedures; emergency guarantees; and recovery and reconstruction after the emergency has been addressed. Enterprises are encouraged to organise emergency drills and make timely adjustments to the plans, as well as take measures such as environmental pollution liability insurance cover to reasonably insure themselves against risks associated with environmental accidents.

Article 15. Enterprises shall carefully consider the ecological function orientation of the area the project is located, and may, in coordination with the government of the host country and community, prioritise such measures as on-site and off-site (e.g., conservation of animal and plant resources that deserve protection near the project location, to reduce adverse impacts on the local biodiversity).

For ecological impacts caused by investment activities, enterprises are encouraged to carry out ecological restoration in accordance with the requirements of the laws and regulations of the host country or common practices in the industry.

Article 16. Enterprises are encouraged to implement clean production, promote recycling, reduce pollution at source, improve resource use efficiency, and reduce the generation and emission of pollutants in the course of production and service/product use.

Article 17. Enterprises are encouraged to implement green procurement and give preference to environmentally friendly products. Enterprises should apply for relevant environmental management system certification and environmental label certification for products in light of the laws and regulations of the host country.

Article 18. Enterprises are encouraged to post their environmental information on a regular basis, and publish their plans on implementation of laws and regulations on environmental protection, including measures taken and environmental performance achieved.

Article 19. Enterprises are encouraged to strengthen their contacts and communications with the government and regulatory authorities in charge of environmental protection in the host country, and actively seek their opinions and suggestions on environmental protection issues.

Article 20. Enterprises should establish the manner of communication and the dialogue mechanism pertaining to their environmental and social responsibilities, take initiatives to strengthen their contacts and communications with communities and relevant social groups, and

seek their opinions and suggestions with respect to the environmental impacts of their construction projects and operation activities through forums and hearings according to the requirements of the laws and regulations of the host country.

Article 21. Enterprises should actively participate in and support local public benefit activities for environmental protection, publicise the concept of environmental protection, and build a good image for themselves in this regard.

Article 22. Enterprises are encouraged to conduct research on and learn from the principles, standards, and practices relevant to environmental protection and adopted by international organisations and multilateral financial institutions.